WAR SURGERY

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FROM FIRING-LINE TO BASE

BY

BASIL HUGHES

D.S.O., M.A., M.B., B.C. (CANTAB.), B.SC.(LOND.), F.R.C.S.
TEMPORARY MAJOR, R.A.M.C., T.F.

AND

H. STANLEY BANKS

M.A., M.B., CH.B.(GLASG.), D.P.H.(CANTAB.)
CAPTAIN, R.A.M.C., T.C.

WITH SPECIAL CHAPTERS BY

LIEUT.-COLONEL L. F. SMITH, C.M.G., R.A.M.C.,
AND MISS C. BILTON, R.R.C., Q.A.I.M.N.S.

AND AN INTRODUCTION BY

COLONEL SIR T. CRISP ENGLISH

K.C.M.G., F.R.C.S., A.M.S.

CONSULTING SURGEON TO THE BRITISH FORCES IN ITALY; FORMERLY TO THE BRITISH SALONIKA FORCE; SURGEON ST. GEORGE'S HOSPITAL, LONDON

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PREFACE

This work is an attempt to describe as briefly as possible the treatment of wounded men from the time of the infliction of their wounds on the battlefield to the time when they leave the base hospital either for duty or for treatment at the different institutions set apart for special kinds of infirmity.

We have endeavoured to describe methods of treatment whereby the stiffness and incapacity which follow wounds may be reduced to a minimum, and which will place severely wounded men under the best possible conditions to benefit from subsequent orthopædic treatment.

The work embodies the newer and up-to-date methods of wound treatment, and older methods have not been discussed.

The chapter on joints contains photographs of specimens which we have prepared, and which we hope will make clear to the surgeon the nature of the synovial sacs with which he has to deal in the case of infection.

Short chapters on burns, amputations, and diseases peculiar to airmen have been included, as little has appeared in the literature on these subjects.

The general health of the troops while in trenches has been discussed, as we are convinced that prophylactic measures mean everything to the soldier when his day of misfortune arrives.

The treatment of fractures has aimed at rapid sterilisation and early secondary suture in order to produce the minimum of stiffness and disability.

We have not included the later treatment advocated for chest injuries, partly on account of insufficient experience in these methods, and partly because the treatment we have recommended has given such uniformly good results.

A special chapter written by Lieut.-Colonel L. F. Smith, C.M.G., on the part played by malaria and dysentery in complicating wounds has been included, as this complication in the Eastern theatre has been a serious problem. This chapter includes the subject of transfusion of blood, which we have used with success in the case of wounds complicated by gas gangrene infection.

The chapter on gunshot injuries of the head will, we hope, make clear the general line of treatment to be adopted. For diagnosis and valuable help in these cases our thanks go out to Colonel Sir Purves Stewart, K.C.M.G., A.M.S.

Abdominal work is based on our experience at a busy casualty clearing station in France, and though the opinions we have expressed may differ from those of many as regards the treatment of these cases, yet our statistics show a recovery of 62 per cent.

An attempt has been made to illustrate the book so as to show as far as possible all points emphasised in the text. For any bad illustrations our apology is that getting photographic material in the East was a difficult problem.

Our experience is gleaned from three and a half years' work both in the Western and Eastern theatres of war, and comprises eighteen months spent with different regiments in the firing-line, eight months with a field ambulance, four months with a busy casualty clearing station in France, and a year at a base hospital in the East.

We find that the Carrel-Dakin treatment, when properly and systematically applied to war wounds, gives results far superior to those that can be obtained by any other system of treatment.

For all shortcomings in this work, and we know they are many, we offer due apologies, but the work has been compiled under active service conditions in the East, where there was no access to any library of reference, and where the climate tends to the lowering of energy and the production of brain-fag.

The work, then, represents three and a half years of purely personal experience. We owe a large debt of gratitude to the higher authorities who personally interested themselves in the work and gave us every assistance. We would also express our thanks to our commanding officer, Lieut.-Colonel L. F. Smith, C.M.G., who under difficult circumstances has also given us every assistance and encouragement; to Lieut. F. C. Sprawson, who has undertaken the heavy work of correcting the proofs and of preparing them for the publishers; to Captain J. T. Carson, R.A.M.C., for providing X-ray prints; to Sergeant-Major Powel, R.A.M.C., for the coloured plates and several drawings; to Mrs. Hughes for other drawings; and to Pte. Garrett, R.E., and Pte. Hale, R.A.M.C.

BASIL HUGHES.
H. STANLEY BANKS.

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INTRODUCTION

This book will appeal to all keen surgeons, for it is founded on practical experience in every part of the field. The most important part of that experience was gained during eighteen months' surgery in the Salonika area. Major Basil Hughes and Captain H. Stanley Banks were working during this time at a hospital which was constantly busy, for it received the majority of the seriously wounded. As Consulting Surgeon to the British Salonika Force, I had the pleasure of seeing the methods adopted and the results.

The work is essentially practical, and represents solid progressive surgery. The many problems arising in connection with the wounded at each stage of their career are clearly discussed and a definite line of treatment suggested for each. Gunshot fractures are perhaps the greatest test of war surgery, and this subject is dealt with in detail. The principles advocated have produced results favourable beyond all expectation, and have very considerably shortened the period of treatment of wounded men.

Two principles are kept to the fore. The first is that an organised plan of treatment for the wounded is essential ; the treatment originated in any one unit should be so planned that it can be carried on and completed in the other units to which the patient is transferred later. Standardisation and continuity of treatment must be established as far as possible, for end-results are again and again vitiated by diversity of methods and discontinuity of treatment. To effect this, Carrel's method was selected as appearing to give the most consistent results, and experience of other methods of wound treatment has not led the authors to modify this opinion. A definite plan of treatment, in which Major Hughes took a chief part, was developed in a certain area ; Carrel's method was instituted as the standard treatment in the units at the front, on the trains, and at the base ; after the healing of the wounds, treatment was completed at an orthopædic depot. This scheme produced most satisfactory results.

The second important principle is that the surgeon and the bacteriologist must work together. Rational wound treatment is impossible without constant bacteriological help, and a large share of recent surgical progress is due to bacteriological research.

The success of Major Hughes's work is due to the fact that he has adopted definite lines of treatment, and has utilised all the guidance and assistance which bacteriological co-operation places at the surgeon's disposal.

T. CRISP ENGLISH.

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WAR SURGERY

CHAPTER I

INTRODUCTORY

The treatment and care of the wounded forms but one branch of the work for which the Army Medical Service is responsible. Few besides those who have had experience in every unit from the firing-line downwards will ever realise what a vast machine or organisation this service is.

The hygiene and care of the troops, the evacuation of wounded men from the field of battle, attention to their wounds on the lines of communication, the provision of transport, the treatment of tropical diseases, and hundreds of other problems which would never occur to the casual observer, have all to be dealt with.

There have been and are still to-day many critics. Criticism is useful if it comes from those who are in a position to criticise—that is to say, if it comes from persons who have had actual experience in every unit of the Medical Services from a regiment to the base.

We speak with feeling on this point, for we have been concerned with all units from the firing-line to the base, and have both seen and realised the almost insuperable difficulties that have been overcome. Any reasonable suggestions towards the improvement of methods or of details have always been readily received and considered by the higher authorities, and if any suggested scheme has seemed feasible, it has been adopted without delay.

It would be absurd for anybody to suggest that an organisation like the Army Medical Service, largely augmented by recruits with little knowledge of army organisation and administration, could go straight into a colossal war like the present one and run like a tuned-up and well-oiled machine. We have all had to learn our job in the present war, and nobody more than the civilian surgeon.

War surgery differs in many ways from the surgery of civilian practice. In the civilian hospitals each surgeon has his own operating-day, and in some instances his own operating-theatre, his own house-surgeon, his own anæsthetist, his own particular instruments, and his own wards. He is

able to see his cases before operation, and to keep them in hospital a day or two in order that they may be the better prepared, and finally he sees the progress and end-results of his cases. In brief, the patients benefit by being seen and attended throughout their convalescence by the same surgeon, while the surgeon benefits by seeing the end-results of his treatment.

In war-time one patient may pass through the hands of many surgeons, each of whom may have different ideas on the treatment of his wound. Thus, one surgeon may prefer to use drainage-tubes, another may prefer saline treatment, another fomentations, another pastes, and so on. This state of affairs is bound to militate against good end-results. It was on this account that in the Balkans a systematised treatment of wounds was tried at the suggestion of the higher authorities, for it was thought that if a certain definite form of treatment could be started as soon as possible after the man was wounded, and this treatment could be carried on until the wounded man reached the base hospital, where the same treatment would be continued, then quicker and better results would be obtained, which would mean less suffering to the wounded man, economy of man power, and a saving of expense to the State.

The Carrel-Dakin system was accordingly instituted. Wounds were dressed with the hypochlorite antiseptics at the field ambulances, and from these units the wounded were quickly transferred to the clearing-stations. Here the wounds were excised and a Carrel-Dakin dressing applied. The patients were sent on to the base hospitals as soon as they were fit to travel, hourly or two-hourly instillations of the antiseptic into their wounds being carried out on the hospital train. At the base hospital sterilisation of the wounds was continued by the Carrel-Dakin method, and when sterile the wounds were submitted to secondary suture.

Transport from the firing-line in the East is difficult, but the way in which the difficulties were overcome reflects great credit on those concerned, for wounded men reached the base in what appeared to be an incredibly short space of time. Wounded men had of necessity to be kept in the base hospitals until their wounds were soundly healed; hence on this front medical officers have been able to follow their cases through and witness the end-results.

An orthopædic depot was established, to which cases of compound fracture of bone, injuries to joints, and the like, could be sent for massage and further treatment, and by visiting this institution the subsequent progress of all wounded men could be seen up to the time when they either returned to duty or were sent on a hospital ship in such a condition that they could look after themselves and jump into a boat if necessary.

Such a scheme of continuity in treatment was the nearest approach to keeping a certain number of patients under one man's care, and the whole system worked admirably. Wounds of appalling dimensions and severity have under this treatment been sterilised and sutured within ten

days of their infliction, which has saved the patient much pain, weeks in bed, much incapacity, and the State considerable expense. The whole treatment, if properly carried out, is painless from start to finish, and many limbs and lives have been saved which would by the older methods have undoubtedly been sacrificed. Severe wounds involving compound fracture of such bones as the femur, tibia, and humerus, have been sterilised and sutured within so short a space of time as a fortnight following the injury, and the patients suffering from such injuries to the legs have been about on crutches at the end of the fifth week.

It has been argued by some that the Carrel-Dakin treatment cannot be carried out on a large scale without an increased staff. This is absolutely contrary to our experience, for we have found it possible to adopt it universally in a large base hospital in the East, where part of an already diminished staff is constantly laid up with tropical diseases.

The equipment required for the carrying out of the treatment is small, and the cost per patient taken over a series of two thousand severe wounds has worked out at seven shillings.

CHAPTER II

GENERAL CLASSIFICATION OF WOUNDS

THE table opposite includes every type of wound so far met with in the present war. Each type calls for separate consideration.

Non-Penetrating Wounds.—This class of wound includes all cases in which the missile has not penetrated the soft parts, and comprises contusions, slight abrasions of the skin, and fracture of bone. It forms a considerable percentage of all wounds in the present war. Contusions may be either superficial or deep, and may vary from superficial hæmatoma to most extensive damage of muscle and even viscera. Contusions are most commonly caused in one of two ways:

1. By a spent piece of shell, usually a nose-cap, though often by a considerable-sized piece of shell-casing.
2. By the falling in of a dug-out or a piece of the parapet, which usually buries the wounded man.

Superficial Contusions may occur on any part of the body, and in the case of the upper arm or thigh are quite sufficient to put a man temporarily out of action, the effect being similar to a severe punch with a closed fist. A superficial contused wound of the abdomen or back should always be looked upon with caution, for a number of cases can be recorded in which a contusion in these situations was apparently slight, but severe damage to abdominal viscera had resulted, calling for immediate laparotomy. Contusions in the region of the loins should be carefully watched, as a number of cases have been followed by hæmaturia, although the contusion itself looked trivial. An apparently simple contusion of the thoracic wall may involve a fracture of one or more ribs, whereas a contusion of the soft parts in the immediate neighbourhood of the spinal column may be associated with severe spinal concussion.

Deep Contusions may involve some or all of the structures down to and including periosteum, and may range from severe bruising to actual tearing and division of muscles and other structures. These wounds are exceedingly painful; there is much swelling, and later, discoloration of the part, and they incapacitate a man to practically the same extent as a fracture. Frequently they are associated with the formation of hæmatoma, either in the torn muscles, the result of injury to vessels, or subperiosteally. Should big nerves be involved, paralysis or paresis of

GENERAL CLASSIFICATION OF WOUNDS.

WOUNDS.

- Non-Penetrating.
  - Contusions.
    - Superficial.
    - Deep.
  - Fracture.
    - Simple.
    - Compound.
- Penetrating.
  - Soft parts only.
    - Small wound of entry.
    - Large wound of entry (penetrating lacerated wound).
  - Bone involved.
    - Continuity of bone destroyed.
    - Continuity of bone preserved.
- Perforating.
  - Soft parts only.
    - Small entry and exit wounds.
    - Small wound of entry and large lacerated wound of exit.
    - Large entry and exit wounds.
  - Bone involved.
    - Continuity of bone destroyed.
    - Continuity of bone preserved.
- Disruptive.
  - With penetration or perforation.
  - Without penetration or perforation.
- Incised and Stab.
  - Bayonet wounds.
  - Knife, knobkerries, etc.
- Burns.
  - Bombs, grenades, etc.
  - Liquid fire.
- Asphyxiating and Poison gases.
  - Shell gas.
    - Lachrymatory shells.
    - Violent poison shells.
  - Drift gas.
- Accidental.
  - Gunshot wounds, barbed wire, etc.
  - Accidental wounds on lines of communication, from mules, mechanical transport, etc.

the group of muscles supplied by the nerve, depending on the amount of damage the nerve has sustained, will result. A deep contusion of the erector spinæ is among the most serious of this class of case; it results in stiffness and pain of a most persistent kind. Deep contusions are serious wounds, in that they put a man out of action for the same length of time that a fracture would, and they call for as much if not more treatment; yet, owing to their nature, they are liable to be overlooked. Much thickening and fibrosis may result, and convalescence be prolonged. Non-penetrating wounds may result in fracture of bone, simple or compound. These fractures usually result from the blowing in of a dug-out, but they can also be caused by a direct hit with a spent piece of shell, and this is most frequent in the case of the ribs. Compound fractures from such causes may be of an extremely extensive character, especially if the roof of the dug-out contain heavy timber.

Examples.—(1) Pte ——, 7th West Riding Regiment, while asleep sustained a fracture of both tibiæ and fibulæ, owing to a direct hit on the roof of his dug-out. The fracture in the case of the right leg was compound and extensive, in the case of the left leg it was simple. On digging him out it was found that a beam in the roof of the dug-out had fallen across both his legs.

(2) Pte. —— and Pte. ——, 5th West Yorks Regiment, were asleep in their dug-out, which just admitted two men, leaving a space of no more than 7 or 8 inches at the most between them. A 5·9 high-explosive shell entered the wall of this dug-out, and burrowed itself into the earth in the small space of ground that lay between the two men. The shell failed to explode, and finally stopped in the ground beneath Pte. ——, fracturing his scapula. The skin covering the scapula was unbroken.

(3) Capt. ——, R.A.M.C., was struck in the back by the shell-nose of a whiz-bang, resulting in the fracture of three ribs. The skin over the site of fracture was unbroken.

Penetrating Wounds

Penetrating wounds form a large and important fraction of the total wounds of the present war. They comprise every case in which the missile has entered the soft parts of the body, but has not emerged.

The wound of entry may vary from an excessively small opening—indeed, in some cases scarcely visible—to a ragged tear of the most extensive dimensions, the so-called "penetrating lacerated wound."

As an example of a penetrating wound of imperceptible dimensions may be quoted the case of a Gunner. A shell burst within 50 yards of this man, and he was perceived to fall. On examination three minutes later he was found to be dead. A most careful search of his body revealed no trace of a wound. Autopsy revealed a wound of the heart and aorta, the missile having entered the thorax from behind through a valve-like opening

in the skin which was so small as to escape a very careful and thorough examination.

Penetrating wounds present considerable difficulties in treatment, as one cannot be sure, without the aid of a skiagram, which direction the missile has taken, or at what depth from the surface it is lying in the tissues.

Certain important points may, however, be found out by observation and palpation. Not infrequently the missile can be felt under the skin at some distance from the wound. If this be so, important information is afforded the surgeon, as not only is the extraction of such a missile easy and rapid, but the surgeon now knows its path, and the surface anatomy of such a track will give him some idea of what important vessels, nerves, etc., are likely to have been damaged. The wounded man will often say that he feels pain in a certain area at a distance from the wound, and can direct the palpating fingers to a spot of maximum tenderness. Careful palpation of such an area will in nine cases out of ten reveal the missile, which can be detected to a depth of from 2 to 2½ inches below the skin surface.

Examples.—(1) Pte. ——, wounded July 1, 1916, presented a penetrating wound about the size of a two-shilling piece just above the right clavicle. He complained of pain at the bend of the elbow. Palpation revealed a circular piece of metal, which was removed. This was a piece of the mechanism of a trench-mortar bomb, and was the size of a five-shilling piece.

(2) Pte. ——, wounded July 1, 1916, presented a penetrating wound just over his right shoulder-blade. He complained of pain and a small swelling in his right groin. Palpation showed a shrapnel ball to be present, and this was removed.

Similar cases are very numerous, but they show what important help the patient can give to the surgeon.

Again, in the case of a small penetrating wound of the thigh it is common to see the thigh very distended and tense, and though pulsation may be felt in both anterior and posterior tibial vessels, it is obvious that a vessel of considerable size has been ruptured. This gives the information that the missile lies deep in the limb, and its immediate removal, with arrest of the hæmorrhage and turning out the blood-clot, is necessary.

It is always worth while to find out from the patient, whenever possible, the posture he was in when he received his wound—*e.g.*, whether he was sitting, lying flat, kneeling, or whether he was walking or running. This is especially important in regard to penetrating wounds of the joints, in particular the knee-joint, for such foreign bodies are more easily extracted with the joint in the degree of flexion or extension that obtained when the missile entered it.

Penetrating wounds of the head, spine, abdomen, and thorax, form the most serious cases, as there is often little outside indication of the internal damage done.

Symptoms in these cases must be the surgeon's first guide.

Penetrating wounds may involve fracture of bone ranging from a groove or gutter fracture or perforation, not destroying continuity, to the most excessive comminution.

An important point to remember is that the size of the wound of entry is no guide to the size of the missile. The skin is a very elastic structure and stretches before the ingoing missile, recovering itself afterwards. Consequently, in most cases the skin wound is smaller than the missile which caused it, and it gives absolutely no indication at all of the extent of damage done to tissues within.

In the case of penetrating wounds of the chest, the skin wound is not an indication of the actual point of entry into the thoracic cavity, as the chest wall is a movable structure. Consequently the skin wound is often at a higher or lower level than the actual point of entry into the pleural cavity. The track of entry is thus valve-like, and this aids in the formation of surgical emphysema.

With the missile there is frequently associated a piece of clothing, or occasionally foreign bodies of a different nature, such as articles which may have been carried in the soldier's pockets. Such have been found most often in the thigh, having been in the trousers pocket at the time of being hit. Thus, coins, buttons, pencils, pieces of string, and in one case a large piece of a miniature New Testament, have been extracted from wounds in the upper thigh, and the presence of such foreign bodies should always be borne in mind when dealing with wounds in this situation.

Penetrating wounds may be the result of rifle or machine-gun bullets, shrapnel bullets, or high explosive of some kind, whether shells, trench mortars, or grenades.

Unless the missile be stopped in its course by bone, these wounds are mostly caused by bullets fired at long range, or by spent pieces of shell. One exception is the case of wounds caused by certain types of hand grenades, where the velocity of the fragments is not great compared with other types of high explosive, and the fragments lodge and remain in the tissues. Such grenade wounds are extremely serious, as they are multiple; the fragments carry in much dirt and clothing, and the skin is frequently burnt, thereby giving rise to shock of severe intensity. Septicæmia is very likely to occur in this class of wound.

Penetrating wounds, especially those resulting from pieces of shell or grenades, are associated with a disruptive effect in the soft tissues which are involved. The explanation of this is a matter of dispute, but it is suggested, and very reasonably, that any missile, whatever its nature, carries in front of it a cartridge, so to speak, of compressed air, and this on entry into soft tissues produces a disruptive effect. The result is that the muscle bundles are forced apart, cut off from their blood-supply, and open planes are formed, along which aerobic and anaerobic infection can spread. In addition to this, the soft parts get a knock-out blow which renders

them, especially muscle, for the time being lifeless, and therefore very prone to infection. This condition of muscle is the so-called "muscle stupor" of the French. Such tissue looks dry, and the muscle seen soon after injury gives the appearance of butcher's meat. It does not bleed when cut, and it does not contract when stimulated. Infection spreads with alarming rapidity in this damaged tissue, and in a few hours a whole limb may be gangrenous. This disruptive effect extends into the tissues for some distance from the wound of entry, a point of the highest importance to be borne in mind by the surgeon, as this damaged muscle forms excellent pabulum for the virulent bacteria of the present war wounds.

Penetrating wounds may be single or multiple. In the latter case shock is an important factor to consider, although no vital part has been involved. Bomb-grenade wounds are almost always multiple, and above all others give rise to very severe shock. One example of this class of case may be cited :

Lieut. ——, while standing at —— Cross Roads after dark, was suddenly riddled with eight machine-gun bullets. Not one of these bullets struck a vital part, yet he died twenty minutes after injury with symptoms of shock.

In all cases of penetrating wounds it must be remembered that the missile with concomitant foreign bodies are still in the tissues, and their early removal is of primary importance, as they are dangerous foci of sepsis. The methods of removal will be referred to in another chapter.

Perforating Wounds

Perforating wounds entail a wound of entry and a wound of exit. They possess an important advantage over penetrating wounds, in that the missile has emerged and no longer remains in the tissues. The actual damage to tissue varies, but on the whole perforating wounds have a better prognosis than penetrating wounds. Perforating wounds are most often the result of missiles fired at close range, and may comprise—

(A) A small hole of entry and a small hole of exit.
(B) A small hole of entry and a large hole of exit.
(C) A large hole of entry and a large hole of exit.

Class A, for the most part, comprises wounds caused by rifle and machine-gun bullets, shrapnel bullets, or small pieces of high explosive. This type of wound is known as the "seton wound," and the damage involved may vary. Thus, a bullet may traverse the thigh, damaging no important structures, both entry and exit wounds healing and leaving no incapacity. Again a similar bullet may traverse the thigh in a direction almost identical with the preceding, and after an hour or two the thigh will be acutely swollen and tender, denoting damage to an artery of considerable size. A seton wound gives an observer some idea what damage

to expect, since the course of the missile is approximately known. Surface anatomy, though useful, is not always a true guide to damage done, because many cases have been seen where the track, judged by the inlet and exit wounds, passed right across the course of such structures as the femoral artery, the sciatic nerve, the brachial artery, etc., without damaging them. Here, again, there are two important points to consider, on which the wounded man can usually give information:

(1) Was he running or walking when wounded ?
(2) Was he lying down or standing still ?

If the condition (1) obtained, then the wound in the skin does not correspond in position with the wound in the deep fascia and muscles at the site of either entry or exit. The skin wound may be separated from the deeper wound by as much as an inch, but usually a little less. The reason for this is obvious, because when the body is in motion the skin is stretched in some parts and relaxed in others. The same phenomenon occurs to a more marked degree if the bullet strikes the part obliquely. The difference in level between the perforation of the skin and that of the deep fascia and muscles by the same missile is very noticeable when operating upon these wounds.

If condition (2) obtained, then the entry wounds in the skin and fascia approach practically the same level, and the inlet and exit wounds give a fairly accurate estimate of the course of the missile.

A seton wound may involve bone in its course, simply perforating it, this being seen most frequently in the epiphyses of the long bones. Clean perforation of bone, however, is comparatively rare. Seton wounds may involve joint cavities, their valve-like nature in such situations being of great value in preventing escape of synovial fluid and blocking the road to infection, for small seton wounds of joints are mostly sterile. A seton wound involving the abdomen or thorax may either give rise to insignificant symptoms—though from surface anatomy it would appear that serious damage had occurred—or they may involve the viscera, causing many perforations in the case of the intestines and serious damage in the case of the lung, liver, or the other solid abdominal viscera.

Seton wounds in the neighbourhood of large arteries are the commonest cause of traumatic aneurysm. Swollen thighs, the result of hæmorrhage, if watched and kept at rest, provided there be good circulation in the foot, slowly resume their normal size, and as the swelling and bruising subside a pulsating swelling with a bruit over it makes its appearance. This has happened in quite a number of cases, not only in the thigh, but in the neck, the upper arm, the forearm, and elsewhere. When once the aneurysm is established and the part has assumed its normal size, operative treatment is simpler and safer than if carried out at once through swollen tissues.

Seton wounds situated in the forearm or leg and traversing the inter-

osseous membrane, especially if the part be swollen, should always be looked upon with caution, and if possible left alone, provided the circulation in the hand and foot are good ; because these wounds, if opened up, often give rise to most intractable hæmorrhage, which is very difficult to control, and when once controlled is very prone to recur. Wounds in these situations frequently involve the anterior tibial or posterior interosseous nerves, giving rise to foot and wrist drop. This type of wound, involving a large trunk such as the sciatic, musculo-spiral, the median, or the trunks of the brachial plexus, may either transfix the nerve or partially divide it. Severe pain, not immediate, but following a few days after the injury, with trophic symptoms later both in skin and muscle, are the result.

Seton wounds about the spine may involve the spinal cord or the large intra-abdominal or intrathoracic vessels. Death in these cases is rapid and painless, and many have been seen in the line.

Class B.—This kind of wound is almost invariably the result of a missile fired at close quarters striking a bone. A rifle bullet in the beginning of its course develops heat to such an extent that the thinly encased lead, though not molten, is soft ; consequently, when a hard structure like bone is struck, the bullet is readily flattened out. Sometimes the lead escapes from its thin nickel casing, portions of it being left behind in the tissues, as shown by the X-ray. In other cases the bullet casing only is found, the lead having gone on. When the bone is struck it is fractured and not only does the flattened bullet, or its components, continue its course, but broken fragments of bone are pushed on before it. The result is a large lacerated wound of exit.

The same result obtains, only to a more extensive degree, when the missile is a piece of shell.

The damage to tissue in this type of wound is often most extensive, owing to severe comminution of the bone entailed. The exit wound, when first seen in the line directly after injury, looks fresh, but very soon the damaged muscle and other soft parts become swollen and œdematous, and by the time the casualty clearing station is reached swollen and apparently lifeless muscle is seen in the wound. Fragments of bone may be protruding into the wound, and in extreme cases a limb may be hanging on by only a few tendons, skin, and other mutilated structures.

Again, the continuity of the bone may not be destroyed, but the bone only chipped. Here the missile, if it be a bullet, has been turned in its course by slight impact with the bone, and as such has caused a large exit wound, with much damage to the soft structures.

Perforating wounds of the head, and often of the thorax, come under Class B.

In the case of the head the missile traverses the bony cranium twice, the exit wound is large, and a quantity of brain matter is usually protruding. A great number of these cases die in the line ; unconsciousness is

instantaneous, the pulse-rate becomes rapid, and death soon follows. A few such cases reach the casualty clearing stations and the base hospitals, but recovery is extremely rare.

Wounds of the thorax belonging to Class B have, with few exceptions, died in the line. In a large number of cases the wound of exit has passed all description, and death has fortunately been instantaneous.

In two cases seen in the line who were still living, the greater part of the lung, which was extrathoracic and had been soiled with trench mud, was washed and put back. The large hole in the thoracic wall was plugged with an ordinary boiled towel, and these cases reached a casualty clearing station. One of them lived for three days and the other for four days after the day of the wound.

This class of wound is met with in the abdominal area, and it is not uncommon to see a large piece of omentum or a loop of intestine protruding from the exit wound. This type of abdominal wound is often conspicuous by the absence of shock. A number of men so wounded have walked from where they were hit to the regimental aid post, and in some cases to the advanced dressing station. They have arrived at the casualty clearing stations little the worse for the journey, and after operation have done well. The extruded omentum or gut is usually soiled, but so long as there is no gross damage to viscera the prognosis is good. One example from many in the line may be quoted :

Sgt. —— was wounded by a rifle bullet on the night of November 20, 1915. The bullet had entered the right lower abdominal quadrant, had turned in its course, and emerged in the left lower quadrant. A large piece of the omentum and small intestine were protruding from the exit wound. He walked to the regimental aid post, a distance of 150 yards. There was no shock, and the man was cheery. He reached the casualty clearing station, and made a good recovery, being heard of later in England.

Class C.—These wounds comprise a large hole of entry and a larger hole of exit connected by a ragged and torn track, which is overhung by a bridge of tissue consisting of skin and deeper structures. This bridge, which may or may not contain such important structures as the femoral artery, the sciatic nerve, etc., is usually in a very torn and bruised condition, and is exceptionally prone to become gangrenous. The disruptive effect produced in these wounds is great, and if a bone be involved in the case of an extremity, complete dismemberment may occur. These wounds are of a very serious nature, owing to the amount of damage done and to the rapid onset in them of virulent infection. They need early and thorough handling in order to save life and limb.

This class of wound is usually the result of a direct hit with a piece of shell of considerable size or a ricochet bullet, and it is surprising what damage a ricochet bullet can inflict.

One instance may be quoted of Pte. ——, who was walking at night along a road 500 yards in front of the German trenches. He was hit on the right side of the head by a ricochet bullet, which took away the whole of the calvarium and scattered most of his brain over a comrade who was with him, but who escaped without injury.

In Class C is included the type of wound caused by large pieces of high-explosive shell where the entry and exit wounds no longer exist as such, the overlying bridge of tissue having been destroyed by the missile. The pieces of shell causing these wounds vary in size and shape, but pieces can at any time be found on the battlefield a foot or more in length, with an edge as sharp as a knife, or smaller pieces, bearing one sharp edge and irregularly rough along the other edges—in fact, an endless variety, all equally deadly, but too numerous to mention, may be met with.

Some of these wounds are of an appalling nature, and almost indescribable. Instances are (1) a sentry completely cut in half at the level of the second lumbar vertebra by a long, sharp piece of shell; (2) complete decapitation of a sentry by a similar piece of shell; (3) anterior abdominal wall carried away, with complete exposure of viscera; (4) both buttocks carried away.

Many similar instances could be quoted. The majority of men with such wounds usually die before they can be got out of the line, and very few, if any, reach the casualty clearing stations. Fortunately, there seems to be little or no pain following the infliction of these ghastly wounds, and the end has invariably been a painless one, at any rate in the case of those dying in the line.

Disruptive Wounds

The disruptive effect produced in tissues by different missiles after penetration has already been referred to. Disruptive phenomena also occur where there has been absolutely no evidence of tissue penetration and appears to be the result of the burst of a large high-explosive projectile in the close proximity of the individual affected.

Disruptive wounds have been observed most frequently to follow the explosion of large trench-mortar projectiles, the so-called "oil-cans." The explosion caused by one of these projectiles is terrific, though the effect is very local. It has happened on more than one occasion that one of these bombs has exploded in a certain traverse and men in the next traverse have escaped without injury. Should, however, the trench be one without traverses, the force of the explosion travels along it, and can be unpleasantly felt at a distance of 200 yards.

A Minenwürfer consists of a thin casing of steel, not more than $\frac{1}{8}$ to $\frac{1}{4}$ inch in thickness, and is tightly packed with high explosive. Only a small fraction of the bursting force is spent in splintering the thin envelope,

leaving the greater part free for destructive purposes. It would appear that within a certain radius of such a burst an extremely powerful centrifugal force is produced, perhaps better designated a "rending" force, which is highly destructive in its effect on the individual.

Similar phenomena are observed when an explosion takes place within a confined space. For instance, if an ordinary Mill's bomb, popularly known as the "Newtown Pippin," explodes in the open its effect is local, and not much is felt of the explosive force at a distance of 30 yards. Should it burst in a trench, the explosive effect is far greater, but should it burst in a confined space like a dug-out, the effect is most destructive.

Within a German dug-out, which was entered after being bombed, all that could be found in the way of human remains were pieces of flesh, hair, and brain plastered on the dug-out wall, while pieces of bone with thoracic and abdominal contents were strewn about the floor. This example will give some idea of the rending force of these small weapons when exploded within a confined space.

In the case of trench-mortars, mutilation of a terrible nature occurs. One example will serve to illustrate this :

Two Signallers were in —— salient. A Minenwürfer exploded close to the signal dug-out. Nothing more was seen of either of these men except one of their lower extremities, which was hanging in the German wire about 150 yards away. It was recovered by a patrol in the evening, and was found to be completely disarticulated at the hip-joint.

It is rather a significant point that in this class of wound disarticulation or, more correctly speaking, avulsion of the limb at the shoulder or hip joint has been more common than avulsion at any other joint, and further instances could be quoted to support this statement.

The Minenwürfer is responsible for a large number of the cases diagnosed as shell concussion.

One fortunate point about these "oil-cans" is that during the daytime they can both be seen and heard, and so men have time to move along the trench and get into a safe traverse.

An interesting case worth recording is that of Major ——, who received a fraction of the explosive force of one of these missiles. It shook him badly and left him rather deaf, but he decided to carry on. Five days later he had a copious clear discharge from his right ear, evidently cerebrospinal fluid. He was sent down to the base hospital, where it was found that he had sustained a fracture of the basis cranii. He made a good recovery.

Incised Wounds

Under this heading come a miscellaneous collection of wounds inflicted with different weapons of war, but all falling within the category of incised wounds. At the field ambulances and casualty clearing stations it was remarkable how very few of these wounds were seen. During a period of three months at a busy casualty clearing station, when active fighting was in progress, not more than half a dozen cases came through. On another front, out of 1,000 wounded men reaching a base hospital, only eight presented wounds that had been inflicted with sharp instruments.

These wounds usually result from hand-to-hand fighting and bayonet charges, and, with the exception of a few cases, are very fatal, the wounded usually dying where they fall.

The commonest weapons used for inflicting these wounds are the bayonet, dagger, knobkerrie, and the butt-end of a rifle.

A bayonet wound may range from a stab of variable depth to a cut 3 or 4 inches in length. The thrust is usually directed either at the throat or the loins. One instance may be recorded of a wounded German who had been lying out nearly twenty-four hours. When he reached the casualty clearing station it was found that his throat was cut across and his trachea was severed, yet no artery of any size had been damaged. The wound was extremely foul and maggots were coming out of the trachea. He died three hours after admission.

A few of our own soldiers have been accidentally wounded with a bayonet through hurriedly getting back into the trenches from No Man's Land, some part of their body, most often the thigh, coming in contact with the point of an upturned bayonet. The authors, however, cannot recall a single case of a wound caused by a German bayonet, though such a wound would probably be severe, seeing that a number of German bayonets are serrated.

There is rarely, if ever, any external bleeding from a bayonet stab, and once it is thrust home the skin and muscles close tightly on the steel, so that a considerable effort is required to extract it. This difficulty is overcome by giving the rifle a half-twist to the left, when extraction becomes easy.

Dagger wounds are short incised wounds of variable length and depth, and of those seen only one was of a serious nature, the blade having entered the peritoneal cavity. This particular case recovered. They differ in no way from stabs and cuts in civil life.

Knobkerrie wounds are very fatal, and death is usually instantaneous. Two Germans reached a casualty clearing station, but died shortly after admission. One had the greater part of his scalp hanging down and a most extensive fracture of the calvarium. The other had a large clean-

cut wound on the right side of his head and an extensive fracture of the basis cranii.

Strictly speaking, these wounds are not true incised wounds, being inflicted with a blunt instrument, but for convenience they are included here.

Wounds inflicted with the butt-end of a rifle may be as cleanly cut as if a knife had been used. They are usually associated with fracture of the bones of the skull and face and are very fatal, few surviving to leave the battlefield.

Bites are not uncommon wounds in close hand-to-hand fighting, and wounds of this nature are frequently inflicted by the Germans. These wounds are not of much importance, and no harm has come of them.

Burns

Burns inflicted by the enemy may result from the bursting of a shell, especially the incendiary type, or from the bursting of a bomb in the immediate neighbourhood of the individual. The extent of these burns varies greatly, and may range from a superficial erythema to most extensive charring. Superficial erythema is usual in bomb wounds, and with it the skin is peppered in many places with minute fragments of dirt and grit which have been carried into the tissues. The uniform to a large extent protects the body ; consequently, it is the face and hands that usually suffer, and many of these cases are seen at the casualty clearing station. The eyebrows, moustache, and part of the hair, are singed, and in not a few cases the eye itself is involved. The whole face and neck are very much swollen, and the eyelids cannot be voluntarily opened.

The back, arms, and thighs, are sometimes involved, but not so frequently as the hands and face.

This type of wound occasions considerable shock, but on the whole the prognosis is good if the eyes are not too badly damaged by heat or particles of grit.

Where extensive charring has occurred, death rapidly follows, if it is not instantaneous. The following is an instance :

—— Battery, R.G.A., was being heavily shelled one Sunday afternoon. Close to this site were some transport lines, and at the time a number of the personnel were sleeping in their bivouacs. A number of the shells fell in these lines, and as soon as the shelling ceased it was found that four men were charred as they lay asleep. Death must have been instantaneous, as they were lying just as they would do when asleep, and from what could be ascertained, they had not moved. A most careful search of their bodies failed to show any sign of a penetrating wound. They were all terribly charred, and the boots that one man was wearing might just have been pulled out of a fire.

Another device, first used by the Germans for inflicting burns, is the

Flammenwürfer. This is an apparatus consisting of a receiver carrying inflammable oil, to which a pipe with a nozzle is attached, and a chamber for storing a compressed inert gas. The oil is projected from the nozzle by the compressed gas, the pressure being kept up by means of a hand pump. Two men are required to work the apparatus, one operating the pump whilst the other carries the rest of the apparatus on his back and directs the flame, which can be projected to a distance of from thirty to forty feet.

Asphyxiating Gas

Asphyxiating gas was first introduced into modern warfare by the Germans at the second battle of Ypres in 1915.

In order for a gas to be effective it must possess the following properties :

1. It must be heavier than air.
2. It must be non-inflammable.
3. It must be poisonous and asphyxiating in considerable dilution.
4. It should be as insoluble as possible in moisture.

For the propagation of a gas through the air the following weather conditions are required :

1. The air should be as dry as possible.
2. A favourable wind is required, a wind blowing from four to eight miles per hour being the most favourable.

The gas is stored under pressure in large iron cylinders, and in this form is carried up to the trenches. Four to six such cylinders are connected together, built into the parapet, and one large delivery tube is attached to the combination. This delivery tube is thrown well out into No Man's Land prior to turning on the gas. In an organised attack several sets of cylinders are used.

Chlorine was the gas first used, but at a later attack, in which one of us was present, a mixture of chlorine and phosgene formed the gas cloud. The gas in this latter attack was at a preconcerted signal turned on between 4 a.m. and 5 a.m. on a dark winter's morning. The gas could be heard issuing from the delivery pipes in No Man's Land, the noise resembling that made by a motor-bicycle, but it could not be seen. Later, as the darkness lifted, dense greenish-white clouds, partly broken up by our own artillery, could be seen slowly travelling with a slight north-easterly wind. Before the arrival of dawn the country was lighted up for some distance round by the bursting of a ceaseless hurricane of shells, which was kept up all that day and well into the next night. The gas from a distance gave the appearance of great masses of cotton-wool, and although the cloud was broken up, yet it was a striking sight to see how closely it hugged the ground.

The phosgene-chlorine mixture is exceedingly poisonous, not only when inhaled, but also when ingested with food which has been exposed to it. This contamination of food is an important point to be remembered when dealing with the wounded men both during and after the attack.

The symptoms and treatment of the condition will be dealt with in another chapter.

Gases are used also in shells. One type is a yellowish gas which causes intense irritation of mucous membranes, especially the conjunctivæ, the so-called lachrymatory or tear gas. This gas also, in certain individuals, produces a gastritis accompanied by persistent vomiting. It was used by the Germans for shelling our own batteries. When the thickest part of the gas has dispersed, a pleasant smell resembling geraniums persists for three or four days, and the ground where these shells have burst is stained a greenish-yellow colour.

Other gas shells used by the enemy are extremely poisonous. These shells make very little disturbance on bursting, and the gas is nearly invisible. It possesses a curious odour, somewhat resembling burning india-rubber.

Gases of a highly irritating kind are used in bombs, the so-called "stink bombs." These bombs are used for clearing enemy dug-outs and subterranean passages. They are of the ordinary jam-pot variety, provided with a detonator, and charged with a fluid which rapidly turns into gas after explosion of the bomb.

To-day every soldier is provided with an anti-gas respirator which affords complete protection against any gas that the enemy may use.

Accidental Wounds

Accidental wounds form a heterogeneous group ranging from wounds of trivial nature to wounds of the most fatal kind.

They may be divided into wounds inflicted in the fighting zone, and those inflicted on the lines of communication.

Accidental wounds in the fighting zone comprise wounds inflicted while in trenches or while out at rest. Of those seen in the trenches, the commonest are tears caused by barbed wire and rifle and revolver wounds, whether self-inflicted or otherwise.

Tears by barbed wire may be anything from a scratch to a considerable-sized rent; sufficient to lay the man up for two or three weeks. All such scratches mean a temporary departure from the line in order to receive the prophylactic dose of antitetanic serum.

Self-inflicted bullet wounds are usually situated on the dorsum of the foot or in the palm of the hand, and can be recognised from the scorching of the skin around the wound of entry. Accidental wounds are usually the result of forgetting to close the cut-off after cleaning the rifle.

Wounds inflicted when resting are usually bomb wounds contracted during bomb practice, and are generally of a very extensive and serious

kind. They are also occasionally seen as the result of accidents at trench-mortar schools and the like.

Wounds inflicted on the lines of communication are for the most part due to transport, and are the result of mule-kicks, runaway horses, machinery accidents, and occasionally rifle bullets.

Though not coming under the head of accidental wounds, yet occurring most frequently on the lines of communication, are wounds due to air raids. Wounds caused by bombs dropped from aircraft are notoriously serious. Not only in these raids have we the wounds caused by the bombs to consider, but wounds caused by pieces of shell from the anti-aircraft guns, which have on several occasions proved both serious and fatal.

CHAPTER III

GENERAL NATURE OF WOUNDS

Wounds of War and Wounds of Civilian Practice.—It must by now have struck all observers how great a gulf separates the present war wounds from wounds seen hitherto in civilian practice. Prior to the war, casualty surgery formed a considerable part of the surgery done in all the big civil hospitals, yet owing to the irregular times of arrival of these cases at the hospital, and to the fact that all such cases need immediate treatment, it frequently fell to the lot of the house-surgeon or the resident surgical officer to deal with them. For the most part, civilian casualty surgery dealt with fracture of bone, simple or compound, usually the result of street accidents, machinery crushes, dock and railway accidents, together with wounds of all classes resulting from street brawls and the like. In addition, incised and lacerated wounds of varying dimensions, burns, septic infections, both of the localised and cellulitic type, formed quite a high percentage of the daily casualty surgery. Yet how rarely did cases of gunshot wounds occur! During ten years' experience both in London and provincial hospitals the authors can only record eight, these being cases of attempted suicide and malicious wounding. Malicious stab wounds are almost as infrequent.

Amongst the very worst wounds seen in civil life, one never saw a case which followed the course seen in the more severe cases of gunshot wounds of the present day.

The explanation of this is not far to seek, for gunshot wounds differ most widely from civil wounds both in the *quality* and the *quantity* of damage done to the tissues involved. It was the failure to recognise these two important points that led to bewilderment and disappointment in the treatment of wounds during the earlier months of the war, when infection of a most virulent and fatal kind flourished, despite active treatment, which in civil cases had proved itself adequate to cope with infection and wounds as we then knew them.

The nature of the wounds that reached England during the later months of 1914 and the early part of 1915 calls for no comment here, but readers will remember, despite the treatment meted out to them, the septic state which persisted in these wounds, especially in fractures, often resulting later in septicæmia and death.

It was evident that there were more extensive changes in the wounded parts than first met the eye, and it became necessary to look in new directions and adopt new methods of investigation and treatment.

History of a Wound.—Much may be learned from the general history of a wound from the time of its infliction up to the time at which the wounded man reaches the field ambulance or the casualty clearing

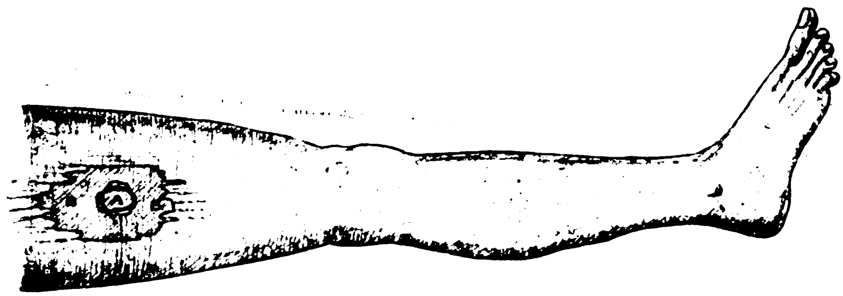


FIG. 1.—*Stage* 1: The figure shows diagrammatically a wound of the soft parts of the thigh immediately after infliction. *A* is the wound of entry in the skin and deep fascia; *B* represents the divided and contracted ends of muscle. Note that the muscle bundles have contracted irregularly, leaving diverticula in its substance; also that from the blind ends of the diverticula a disruptive effect has spread along the muscle substance in both directions.

station. Let us take, for example, a penetrating wound of the soft parts of the thigh where the missile is a piece of high explosive about three-quarters of an inch square, and study the clinical picture of such a wound up to the time that the casualty clearing station is reached.

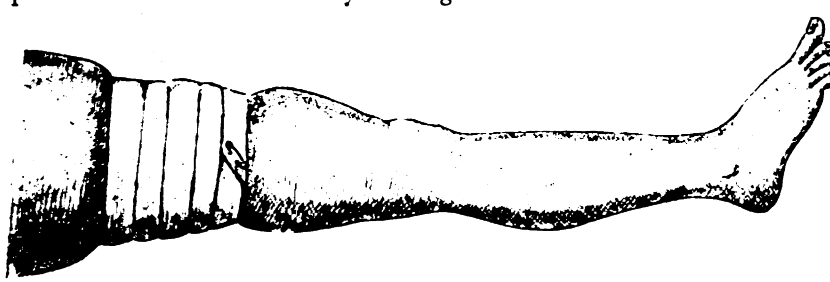


FIG. 2.—*Stage* 2: Note the swollen condition of the whole thigh. The dressing, which has been loosely applied, is now acting like a tourniquet and constricting the limb. This is the stage of reactionary or traumatic œdema.

When first seen in the trenches or on the battlefield, there is the usual wound of entry with a small amount of blood exuding. Hæmorrhage in any considerable quantity from these wounds is a rare incident in the period immediately following their infliction. There is little pain, the whole thigh appears to be "stunned," but there is considerable shock, the wounded man looking very blanched and the pulse-rate often being 110 or more. There is at first little or no swelling of the wounded part. It is at this stage that the first field dressing or shell dressing is applied, and

the wounded man is carried down to the advanced dressing station or the regimental aid post.

Œdema of Tissues of Wounded Part.—It has often been necessary to detain him at one of these two stations. When this has been the case we have observed that within the next hour or two the limb presents a different aspect—in fact, on several occasions the following change has occurred within half an hour of injury. The limb commences to swell, and the swelling develops with extraordinary rapidity, necessitating the cutting of the bandage securing the dressing. The swelling is not only confined to the tissues in the region of the wound itself, *but it involves tissues in the limb at a considerable distance from the wound.* At this stage the limb becomes acutely painful, owing to the severe stretching of the fascia lata, and at the same time swollen œdematous muscle herniates from the wound of entry and completely occludes it.

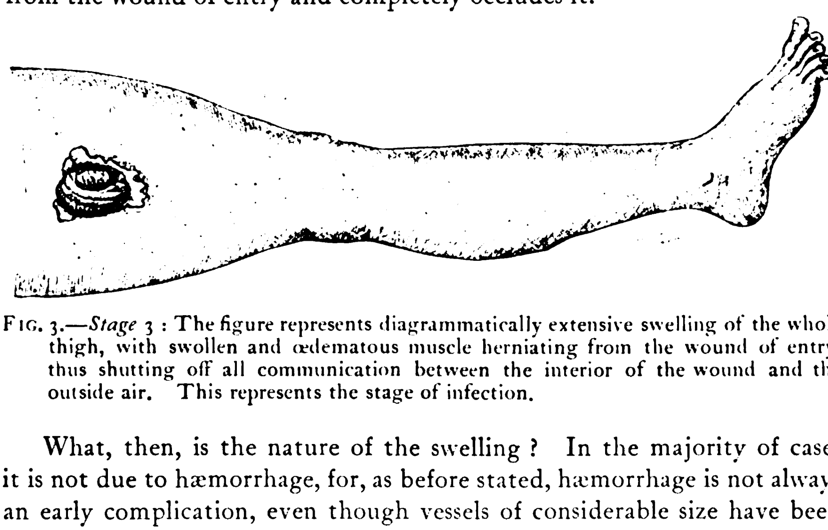


Fig. 3.—*Stage* 3 : The figure represents diagrammatically extensive swelling of the whole thigh, with swollen and œdematous muscle herniating from the wound of entry, thus shutting off all communication between the interior of the wound and the outside air. This represents the stage of infection.

What, then, is the nature of the swelling ? In the majority of cases it is not due to hæmorrhage, for, as before stated, hæmorrhage is not always an early complication, even though vessels of considerable size have been divided, because the blood-pressure falls immediately owing to the shock occasioned by the wound. It is not due to gas-formation, as these limbs are not tympanitic, and it is as yet too early for the formation of gas. It is due to an acute reactionary œdema occurring in the damaged tissues, and this œdema constitutes the first change.

Interference with Circulation.—This œdema is a potent cause of early gangrene, through the direct interference it exerts upon the circulation. The swollen tissues, prevented on all sides from expanding by the tense fascia lata, bring about an ever-increasing compression on the vessels of the limb. The circulation in the œdematous muscles is poor, and in addition to their œdematous condition other striking changes are present by the time the casualty clearing station is reached.

Infection of the Swollen Tissues.—Some twelve hours or less after the infliction of the wound the patient arrives at a casualty clearing station, where every convenience exists for surgical intervention. His

limb is very swollen ; it may or may not be at this time acutely tender, and it may or may not be tympanitic and discoloured.

After excision of the wound of entry and opening up the track of the missile, there exudes a dirty brownish-black discharge with an offensive fæcal odour. On enlarging the wound in the direction of the long axis of the limb and cutting through the fascia lata, œdematous muscle at some distance from the wound herniates out, and probably by this time some gas escapes also. This herniated muscle is characteristic in appearance. It resembles butcher's meat, having a dry, lifeless look ; it does not bleed when cut, and it does not contract when stimulated. Though it is still living, it is exceedingly apt to die, and while in this œdematous condition it is very prone to infection—indeed, infection is often present in it by the time the casualty clearing station is reached. That part of the muscle which helps to form the track of the missile is irregularly divided, and immediately contracts after infliction of the wound. By the irregular contraction of the divided muscle fibres diverticula are formed. The divided surfaces of the muscle soon become covered with a greyish-green stinking membrane. Hence a potential space containing diverticula lined throughout with an evil-smelling infected membrane results, and from this focus infection spreads.

Muscle in this state is neither able to keep up its effluent lymph-flow, nor to empty itself of stagnating venous blood. Soon the stagnating blood coagulates in the veins within the muscle substance, and death of the muscle results.

How are these changes in the muscle tissue brought about ?

Disruption and Stunning of Affected Tissues.—Here there are diversities of opinion, but it seems very probable that there are two factors at work : firstly a disruptive effect, already alluded to in Chapter II. ; and secondly a knock-out blow on the muscles in the immediate vicinity of the wound. That such paralysis of muscle is immediate cannot be denied by anybody who has seen these wounds directly after their infliction in the line, for there is immediate paralysis of both motor and sensory functions. There is no fibrillary twitching of the muscle to be seen, and the damaged muscle, when cut or stimulated, does not contract or bleed, and the whole surroundings of the wound are painless. This is borne out by the fact that we have on more than one occasion performed a painless amputation of the guillotine variety immediately after infliction of the wound through proximal tissue. What is the extent of the damage to muscle in a penetrating wound ?

Damage to Tissues distant from the Wound.—Here, again, there is diversity of opinion, but the salient fact is that *the damage sustained by the tissues is confined not only to the wound itself, but involves the tissues at some considerable distance from the wound.* It was failure to recognise this important point that led to failure in the treatment of earlier cases, and it is to Colonel Gray that credit is due for first pointing

this out. He practised and urged most strongly the importance of free incision and excision of wounds until the limits of damaged tissue had been reached.

It is a common phenomenon, and many instances have occurred to demonstrate it, that a bone may be struck and fractured, not at the actual point of impact with the missile, but at another point some distance away. Similarly, many cases have been met with which demonstrate that a limb struck at any one point may show little apparent damage in the immediate vicinity of the wound, but at a point a considerable distance away there is a large hæmatoma in the soft parts, though the missile itself is nowhere near the latter situation. Here again there is a diversity of opinion, for some have pointed out that microscopically there are no gross changes to be seen in tissues distant from the wound, whereas other microscopists have held the reverse view. Amongst such conflicting opinions it is difficult for a surgeon whose experience in the early treatment of gunshot wounds has been limited to know which view to accept, but all surgeons who have had experience at busy casualty clearing stations will agree that clinically Colonel Gray's view is correct. Those who have had experience in the line, and have had the opportunity of seeing wounds which never leave the line, cannot but be impressed with the truth of this salient feature.

Does œdematous and stunned muscle ever recover ?

The answer to this question will depend upon the length of time that elapses between the reception of the wound and efficient surgical treatment. If early incisions be made through the skin and deep fascia into the substance of the muscle which will allow the muscle to expand freely, and at the same time remove the constricting influence of the fascia lata with the concomitant inhibitory effect on the circulation, then it is quite possible that the affected muscles may recover. If, on the other hand, the constriction of the deep fascia be not relieved, the muscle rapidly dies, and forms suitable pabulum for the growth of micro-organisms, especially *B. perfringens* and the more virulent streptococci.

Latent and Manifest Damage of Tissues.—The nature of the damage inflicted on the tissues will, for the most part, depend upon the distribution of the force of the missile, and it is important to recognise that, *ceteris paribus*, the more extensive the superficial injury, the less the probability of damage to deep structures, and consequently the better the prognosis. A travelling missile has a definite and fixed amount of kinetic energy, represented by the formula $\frac{1}{2}m.v^2$. It is obvious that if the greater part of this energy be expended in damaging superficial tissues, there is but little remaining to produce deeper and consequently more important damage. Again, in the case of a penetrating wound, where all the kinetic energy of the missile is expended in damaging the tissues, there is likely to be far more destruction than in the case of a perforating wound where part only of the energy is so expended. If, on the other hand, the missile

impinges on a structure more resistant, such as bone, its kinetic energy may be suddenly reduced to zero, and what might have proved a perforating wound of the soft parts only now becomes penetrating, with a consequent excess of tissue destruction.

Where we have to deal with extensive external wounds we can be sure that the force of the missile has expended itself in producing visible external damage, but where the wound happens to be of the penetrating variety, involving or not fracture of bone, we must reasonably infer that the damage to tissues, though for the most part latent, has nevertheless occurred,

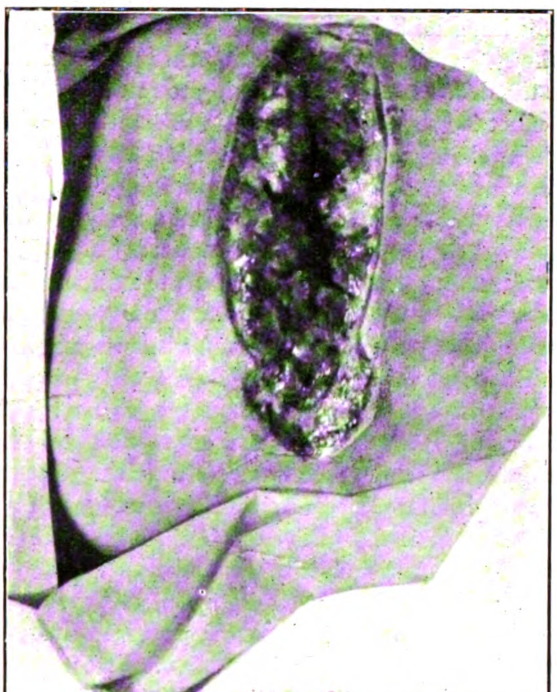


FIG. 4.—Perforating wound of back caused by a piece of high explosive. There was no visible damage externally beyond a small wound of entry and exit. Note the internal damage which is apparent after the wound has been opened.

and that the force of the missile has almost entirely expended itself in producing internal damage.

Wounds of the abdominal and thoracic viscera are interesting in this connection. Here we sometimes see extensive wounds where a large piece of the abdominal wall has been carried away right down to the peritoneum, sometimes tearing this latter structure, and yet the abdominal viscera have escaped injury, the force of the missile in this case being wholly expended in producing external visible damage. On the other hand, a contusion of the abdominal wall caused by a nose-cap may be associated

with extensive tearing of the liver, kidneys, or even of a hollow viscus, the force in this case being spent in causing latent or invisible internal damage. Again, a small penetrating wound of the abdominal cavity, showing but little external damage, may hide extensive laceration of the hollow or solid viscera.

Solid viscera, such as the liver, spleen, or kidneys, show when wounded exactly the same disruptive effect and swelling as has already been described in connection with the soft parts of the thigh. Penetrating wounds of the brain illustrate important and interesting phenomena. Here the kinetic energy of the missile is expended in penetrating the outer and inner tables of the skull ; the inner table is splintered, thus further reducing the kinetic energy, and the splintered fragments are further pushed on by the missile and penetrate the dura mater, finally coming to rest in the brain substance.

A similar effect is produced in the brain substance as was produced in the thigh muscles already alluded to ; there is a traumatic œdema. On trephining these cases there is at first no pulsation of the dura to be seen ; soon, however, the tension relieves itself, and blood-clot with fragments of bone, and sometimes the missile, are " vomited " out of the hole in the dura mater, and pulsation returns. Should the missile have lodged near the motor centres or in the occipital lobe, temporary monoplegias may be present or restriction of the fields of vision. We have treated a large number of cases where the monoplegias vanish in from seven to ten days after trephining. Transient monoplegias are merely symptoms of a traumatic œdema produced in the cerebral cortex, and disappear as the œdema subsides. The head illustrates well the effect of traumatic œdema occurring within a closed unyielding space, and trephining is just as urgent here as free incision of the deep fascia for the relief of traumatic œdema of the thigh structures already referred to.

Multiplicity of Wounds.—War wounds, again, differ from wounds seen in civil life in that they are in a large percentage of cases multiple. Multiplicity of wounds is associated with shock of a severe type, and patients suffering from shock, with the consequent fall of blood-pressure, are far less able to resist infection in the first day or two following their wounds, which is the important and critical period. Bomb wounds and air-raid wounds are notoriously malignant in this respect. Multiple wounds inflicted with hand grenades may cause such intense shock that a man so wounded may die before he can be brought back to receive attention. This has frequently happened to men on patrol. Severe cases that recovered sufficiently to reach a casualty clearing station have in the majority of instances died from a combination of shock and infection. The German hand grenade is a truly pernicious weapon, being charged with screw-heads, nails, and every kind of roughened small missile, all of which cause incalculable damage to the tissues, besides carrying in clothing and trench mud.

Statistics.—Multiplicity of wounds makes the compilation of statistics

a very difficult problem. Such a combination of wounds may exist in the same individual that he may succumb to any one of them, yet had not the other wounds been present he might well have recovered.

For example, Pte. ——, wounded July 5, 1916, had a penetrating wound of the skull and a penetrating wound of the abdomen. The wound of the abdomen involved six perforations of the small intestine. These were stitched up and the abdomen was closed. Simultaneously he was trephined by another surgeon, and ten days later died of meningo-encephalitis. His bowels had moved, he had recovered from the vomiting caused by the post-operative intestinal inertia, and the abdominal condition at the time of death was in every way satisfactory, yet this case must be classed as a death in which the abdomen was involved.

Again, Pte. ——, wounded July 10, 1915, had a perforating wound of the left knee-joint, a compound comminuted fracture of his right femur, and a compound comminuted fracture of his mandible, with a laceration of the soft parts of the face. Both face and knee-joint wounds were doing excellently, but he died as the result of gas gangrene which had supervened in the right thigh. It is almost certain that this soldier would have recovered from the wounds of the knee-joint and face had not gas gangrene toxæmia from the wound in his right thigh supervened and caused his death, yet this case must rank as a death in which the knee-joint had been penetrated.

It is multiplicity of wounds that makes statistics of the results of treatment of any one kind of wound, such as penetrating wounds of the knee-joint, penetrating wounds of the head, etc., unreliable; for, strictly speaking, a fair estimate of the results of treatment of any one class of wound can only be arrived at when this particular class of wound exists uncomplicated.

Transport.—In civilian practice a wounded man is able to receive early and adequate surgical treatment, either at his own home or at a hospital. In warfare all he can receive on the battlefield is first-aid treatment, and not until he reaches the field ambulance or the casualty clearing station can adequate surgical measures be carried out. The time that elapses between his being hit and arrival at one of these units varies with conditions. He may reach the unit in as short a space of time as two to six hours after being wounded, or it may be as late as thirty-six or even seventy-two hours. Part of the journey from the battlefield is either along communication trenches or over the open, and, whichever route be taken, this part of the journey is bound to be rough. From the advanced dressing station the remainder of the journey is completed by motor ambulance, often over rough roads. Hence, if the wound be one involving bone, such as a compound fracture of the thigh or leg, or if it be one involving the thoracic cavity, the abdominal cavity, or the head, such a journey has an unfavourable influence on the wounded parts and the man's general condition.

Transport between the battlefield and the casualty clearing station is,

then, another complication which can alter for the worse the nature of any extensive wound.

Traumatic Anæsthesia.—The immediate anæsthesia or "stunning" of the tissues which follows penetrating or perforating wounds in the case of extremities, has proved beneficial in the class of wound in which the limb is hopelessly shattered. Where this condition exists, and it is not immediately possible to move the wounded man out of the trenches, most extensive shock results from leaving such a limb attached to the body, and this is further increased by transport. We have on more than one occasion found it necessary to perform immediate amputation in the trenches, and such a procedure has proved itself to be absolutely painless, even when the amputation has been carried out through tissues immediately above the wound. The immediate improvement in the condition of the patient consequent on such a procedure has been most striking. The cases did well, and were heard of later in England.

Injury of Bone.—Wounds involving bone differ very materially from those seen in civil practice, for although in the latter, fractures are either simple or compound, the fractures as they exist involve but little comminution, and there is usually a minimum of damage to the soft parts. On the other hand, in the case of gunshot wounds, bone comminution of the gravest kind is usually the rule, and associated with it there is extensive damage of the soft structures. Often, indeed, there is considerable loss of continuity in the bone, amounting in some instances to 3 inches or more, and this comminution may involve an important joint. For instance, a gunshot wound fracturing the femur at the junction of its middle and lower thirds may easily involve the knee-joint.

Anatomy of Wounded Part.—The anatomy of a part, especially of a limb, may be profoundly modified as the result of an extensive gunshot injury. Thus, structures like the sciatic nerve, the posterior tibial nerve, etc., and arteries of considerable size, together with the tissues which surround and support them, may be so involved and displaced as to render their identification impossible except to those who have had considerable experience. Thus, when a wound is explored, hæmorrhage may occur from a large vessel which has been hopelessly displaced from its normal anatomical position. When dealing with these wounds, therefore, a thorough knowledge of the more refined anatomy of the part is absolutely essential both from the point of view of speed in operating and avoidance of inflicting further damage on important structures that have been displaced from their normal positions. A surgeon who undertakes the treatment of war wounds must know his anatomy intimately, as almost every fresh case that he meets differs from any that he has already seen, and it is this feature that makes war surgery so fascinating a study, and so much more difficult than the ordinary clean surgery of civilian practice.

CHAPTER IV

THE BACTERIA OF WOUNDS

In broad general terms the three great complications of wounds are shock, hæmorrhage, and sepsis. Of these, the first two play their most important part in the wounds which kill almost outright or within a very short time. Such wounds can be of little interest to the surgeon. He must concern himself solely with the potential survivors among the wounded ; and in this great class, while the conditions of shock and hæmorrhage still require a considerable measure of attention, yet by far the greatest complication to be dealt with and mastered is that due to sepsis. It is with just pride that the war surgeon can now say, that thanks to the discoveries of the past two years, sepsis in wounds is rapidly assuming a position of much-diminished importance, and shows signs of being conquered in the near future as absolutely as it has been overcome in the operative work of civil surgery. The difficulties of destroying war wound sepsis have given rise to problems infinitely greater than those which Lister set himself to solve in civil surgery ; but at last the reward of much difficult and painstaking work is at hand in a mortality and disablement rate from wounds which steadily and even rapidly decreases with every month that passes.

Every layman is familiar with the fact that sepsis in wounds is due to the action of certain minute forms of vegetable life called *germs*, *bacteria*, *or micro-organisms*. He understands that were it not for the introduction of these micro-organisms into a wound, the latter would gradually heal without the unpleasant and dangerous consequences associated with the various forms of inflammation. Such matters have long been common knowledge, and need not detain us here. Our purpose in this chapter is to give a brief account of the various groups of bacteria which may be found in wounds, and of the characteristics and mode of action of such bacteria. These matters will, in the first place, be dealt with in a general way, prior to a consideration of each particular group seriatim.

General Characters of Micro-Organisms

(*a*) **Function in Nature.**—They are the great destructive agents of all organic material. They purify the earth by resolving effete organic products into harmless simple chemical substances, gases, and elements. This is done in many stages, most of them offensive. There is liquefaction

and production of many foul gases and of poisons in the process, but it is Nature's way of removing dead and inert organic matter, and the net result is the disappearance of the tissue and yielding up of its ultimate constituents, carbon, hydrogen, oxygen, nitrogen, sulphur, and phosphorus, to enrich air and soil. So far their function is beneficent.

(*b*) **Function in Wounds.**—Unfortunately for us, however, some of these organisms have acquired the habit and power of breaking down living tissue as well as, or instead of, dead matter. Among these are classed those organisms which invade wounds and give rise to all the phenomena of sepsis. In wounds the barrier of an unbroken skin is removed, and there is direct access of micro-organisms to tissue in which many of them can live and exert a destructive action similar to that which obtains in the realm of dead and effete organic matter. The result of such action is what we know as sepsis, gangrene, etc., and it is our business to resist such action most strenuously. Hence the whole art and science of the treatment of sepsis in wounds is concerned with the exclusion, destruction, and elimination of micro-organisms.

(*c*) **Classification.**—The micro-organisms associated with wounds are minute plants which almost all belong to the order of *lower bacteria*.

(*d*) **Size.**—They are so minute as to require a special unit for their measurement—namely, the micron (μ), which is equal to one thousandth part of a millimetre. The known organisms found in wounds vary in size from about 0·7 μ (*e.g.*, staphylococcus) to 15 or 20 μ (*e.g.*, *Spirillum Vincenti*). They are commonly examined at a magnification of 1,000 diameters, and their measurement in microns is then the same as their apparent size in millimetres.

(*e*) **Morphology.**—They consist of little masses of protoplasm surrounded by a capsule of the same substance, somewhat modified. In some varieties the capsule is unusually thick, and can be easily demonstrated —*e.g.*, pneumococcus and *B. perfringens*.

They exist in three main forms :

1. Cocci or Micrococci.—Cells globular ; division occurs in one, two, or three directions of space.
2. Bacilli.—Cells rod-shaped ; division in one direction only, transverse to long axis.
3. Spirilla.—Cells twisted spirally like a corkscrew ; division only transverse to long axis.

1. Cocci.—These are divided into certain subgroups:

(*a*) *Streptococci* divide in one plane, and the individuals adhere, forming a chain. The chains are roughly classified as " long " when the number of members is more than six or eight, and " short " when the number of members is less.

(*b*) *Tetracocci or tetrads* divide in two directions, and commonly

form tetrads or bundles of four cocci—*e.g.*, *Micrococcus tetragenus*.

(*c*) *Sarcinæ* divide in three directions, and form bales or packages of cocci.

(*d*) *Staphylococci* divide irregularly to produce masses resembling a bunch of grapes; they are of small size (0·7 μ).

2. Bacilli.—These may be "short" or "long" (1 to 9 μ), slender or thick, and have rounded or square ends. They may be motile or non-motile, and sporing or non-sporing. Many bacilli when viewed suspended in fluid in a "hanging-drop" preparation under the microscope are motile; others are quite still. The motility is due to whip-like processes called flagellæ attached to the sides or ends of the bacilli. The lashing of the flagellæ in a fluid medium gives rise to the movements of the bacilli. The movements may be active or slow, and of various types, such as rolling, twisting, whirling, darting, or slow progression. Motility is made use of in the classification of organisms—*e.g.*, to distinguish members of certain groups of bacteria, such as the coliform group.

Spores are little rounded or oval masses surrounded with a tough resistant capsule. They become formed in the substance of certain kinds of bacilli—*e.g.*, *B. perfringens* and *B. tetani*—when conditions are unfavourable for growth and reproduction. In this form the bacilli can outlive adverse conditions such as lack of food material and moisture, or submission to extremes of temperature. Spores can successfully resist the temperature of boiling water (100° C.) for a short time; they are killed by steam under pressure and by dry heat at a temperature of 135° C. or above.

3. Spirilla are easily distinguished by their characteristic curved or spiral shape. There are not very many varieties found in wounds, the commonest being the *Spirillum Vincenti*, which may be found in association with a long fusiform bacillus, *B. fusiformis*. These are the organisms of Vincent's angina, which is a form of sore throat associated with a necrotic condition in the fauces. In wounds these organisms are also associated with necrotic or gangrenous tissue.

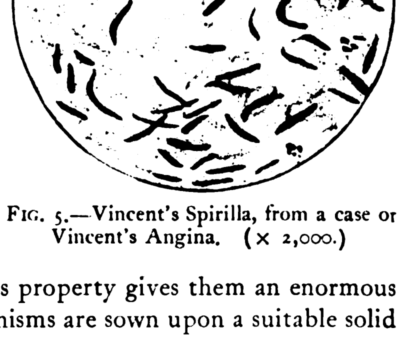


Fig. 5.—Vincent's Spirilla, from a case of Vincent's Angina. (× 2,000.)

(*f*) **Reproduction.**—Micro-organisms reproduce themselves by fission or by sporulation. The former method consists of simple division of each individual into two. Under favourable conditions fission may take place twice or thrice within an hour, and this property gives them an enormous potential rate of increase. When organisms are sown upon a suitable solid culture medium which is incubated at 37° C. for twelve to twenty-four

hours, "colonies" are formed on the medium, and each of these colonies consists of millions of individuals aggregated together, all of which have been formed by fission from one individual during this period.

Sporulation is an alternative method of reproduction practised, in addition to fission, by certain bacilli. Sporulation is observed typically when the bacilli are placed under unfavourable conditions for growth—*e.g.*, in unsuitable surroundings as regards food-supply, moisture, temperature, etc. Under such conditions reproduction by fission stops, and there appears within the body of the bacillus a little refractile speck which enlarges to form the typical round or oval spores. When these are completely formed, the remainder of the body of the bacillus shrinks and disappears. Spores may remain in this dormant condition for a prolonged period, and at any time, when the conditions become again favourable for growth, they develop again into the full bacillus (vegetative form) and fission proceeds as before.

Spores are surrounded by a tough envelope which is extremely resistant to heat, drying, and antiseptics. This makes their destruction a somewhat difficult process. The chief spore-bearing bacilli in wounds are the anaerobes associated with gas-gangrene production. The direct destruction of such spores in wounds would be a most difficult problem. Their destruction is commonly indirectly achieved, however, by taking advantage of the fact that they tend to anchor themselves to dead tissue in wounds; such dead tissue or slough, containing spores, is readily acted upon by the hypochlorite antiseptics—*e.g.*, "Eusol" or "Dakin's solution." These, with the help of the phagocytes, rapidly dissolve sloughs and cause the spores to be swept away from the wound surfaces. By this means the most foul gangrenous wounds are often rapidly freed from spores within a few days.

Spore-formation is the source of much difficulty in regard to the sterilisation of material such as culture media and apparatus, surgical instruments, dressings, etc. Owing to the resistant nature of the spores, sterilisation must be performed by the use of high temperatures or of very strong antiseptics. With regard to high temperatures, moist heat is the most useful. Sterilisation may be carried out by a single exposure of the material to a temperature of 120° C. for twenty minutes in a steam steriliser or autoclave. In the case of glass apparatus, it is usually more convenient to employ dry heat in a hot-air steriliser. The temperature employed in this method should reach 140° C. if applied for forty-five minutes, or 150° C. if applied for thirty minutes. Where such high temperatures injure the material, sterilisation may be effected by the "intermittent method"—*i.e.*, by applying steam at 100° C. for twenty minutes on each of three successive days. This is conveniently performed in Koch's steam steriliser. In this way the vegetative forms are first killed off, leaving only the spores. The latter tend to develop into vegetative forms during the first period of twenty-four hours, and are killed off by the second sterilisation. The third sterili-

sation is for the sake of safety, in order to kill off, after development into the vegetative form, the few spores which may have escaped the second sterilisation.

Biology of the Bacteria of Wounds

A. **Oxygen.**—Certain of these bacteria require uncombined oxygen for their growth and development (aerobes). Others will grow only in the absence of uncombined oxygen (anaerobes). A third group are more or less indifferent to oxygen, and are able to grow either in its presence or absence (aerobes and optional or facultative anaerobes). Examples of the aerobic bacteria are *B. subtilis* and most varieties of diphtheroid bacilli; of the anaerobes, *B. perfringens* and *B. tetani;* and of the aerobes and facultative anaerobes, streptococci, staphylococci, and *B. coli.* Certain members of the latter group are sometimes isolated more readily by anaerobic culture.

B. **Food.**—For their nourishment these bacteria absorb, by a process of osmosis, diffusible albumens through their capsules. In artificial culture media the aim is to provide suitable and convenient albumens for their consumption. For this purpose it is preferable to select, if possible, albumens of a type to which the particular organism under cultivation has been accustomed in its parasite growth in wounds—*e.g.*, blood-serum in the case of *B. influenzæ*, which invariably utilises that protein when growing in the body tissues. Many of the more delicate organisms found in wounds, such as pneumococcus, *B. influenzæ*, etc., require a much richer protein medium than others. For such cases the additional protein may be added to the ordinary media in the form of whole blood, blood-serum, ascitic fluid, legumin, trypsinised brain tissue, meat, and egg. Such enriched media are also most useful for general cultivation of organisms where a vigorous growth is required—*e.g.*, in the preparation of autogenous vaccines. In some cases it is preferable to make culture media specially rich in carbohydrates, such as glucose or lactose, or in glycerin, etc. This particularly applies to those organisms which ferment carbohydrates vigorously—*e.g.*, *B. perfringens*, which forms large quantities of acid and gas from muscle and other sugars. In such cases the addition of glucose to the ordinary culture media is a distinct advantage. Carbohydrates are added to media to assist also in differentiating the members of certain groups of bacteria. Thus, lactose is added to special media used for differentiating the coliform group, some of which are lactose fermenters and others non-lactose fermenters.

The purpose here is simply to indicate how varied are the food requirements of bacteria in artificial culture. Fuller notes upon cultural media and methods will be found in the Appendix.

C. **Fermentation, Putrefaction, and Gas-Production.**—These processes, world-wide in nature, are due to the agency of micro-organisms. They demand consideration here because they occur, to a greater or lesser extent,

in all wounds and in all artificial cultures of organisms. Moreover, they afford a key in particular to the action of the great and important group of anaerobic bacteria in wounds, and, as such, are entitled to the most scrupulous attention.

In Nature these are the phenomena by which bacteria destroy and break down organic matters, and finally resolve them into their elements. The changes are brought about by means of enzymes or ferments which become elaborated by the bacteria during the course of their growth. It is in this way that dead or effete animal and vegetable products and remains disappear from the earth, and liberate their elemental constituents, C, H, O, N, S, and P, to enrich soil and air. Such destruction necessarily takes place in various successive stages, the chemical compounds formed at each stage becoming simpler and simpler until the end-products, gases and elements, are reached. It is thus, for example, that sewage becomes purified by the "septic tank" system, and that polluted rivers regain in time their purity.

Fermentation is the splitting up of carbon compounds, such as starches, sugars, and fats, into simpler products through the agency of micro-organisms. The brewery provides us with a popular example in the fermentation of the maltose of the grain. The yeast plant is employed, and the enzymes formed during its growth break down the maltose to form, among other products, the simpler sugar glucose, from which again, by the same action, is produced alcohol and carbon dioxide gas. In the brewery fermentation is checked at this stage. If, however, no check be applied, fermentation may proceed considerably further—*e.g.*, to the stage of producing acetic acid from alcohols. At the acid-production stage fermentation tends to stop naturally owing to the inhibitory action of the acid produced on the growth of the organisms.

These reactions may be represented chemically as follows:

Glucose = alcohol + carbon dioxide.
Alcohol + oxygen = aldehyde + water.
Aldehyde + oxygen = acetic acid.

In wounds and in artificial culture media fermentation of carbohydrates and fats by the organisms commonly proceeds until acids and gases are produced. Thus, in wounds the action of *B. perfringens*, which is associated with practically all cases of gas gangrene, is primarily one of splitting up of the muscle and other sugars into acids and gases, and only in the late stages does it exert any destructive action on proteins or albuminous substances. The gases associated with fermentation are inodorous, such as CO_2, CO, H, CH_4, and many other gaseous hydrocarbons. In gas-gangrenous wounds, which, especially in the latter stages, are associated with the most foul odours, the odour is due, not to the gases of fermentation, but to the sulphurous gases of putrefaction. In culture media fermentation of various sugars and carbon compounds is commonly

employed as a bacteriological method of differentiating the various members of groups of organisms which may be morphologically and otherwise exactly similar. The most common and useful of the sugars and carbon compounds employed for the organisms of wounds are glucose, maltose, saccharose, mannite, dulcite, arabinose, raffinose, glycerin, inulin, and salicin. These are added to peptone-water or, better, to sugar-free broth, in a strength of 0·5 per cent. Various methods are used for demonstrating gas-production from these sugars—*e.g.*, (1) Durham's tube method; (2) Hiss's serum-water method; and (3) "stab" or "shake" culture method (see Appendix). Acid-production is shown by using litmus solution in the medium as an indicator. It is observed that certain degrees of fermentation are constantly produced by particular organisms, and these become recognised as standard characteristics of the organisms concerned. Such characteristics provide one means of differentiating the members of groups. For example, the various streptococci, coliform bacilli, and anaerobic bacteria found in wounds, all lend themselves in particular to differentiation by this method.

Putrefaction is the splitting up of proteins or albuminous substances into simpler bodies through the agency of micro-organisms. Its action in Nature is well known and widespread, and, as in the case of fermentation, it is a common phenomenon also in wounds and in artificial culture media. The putrefactive process takes place in several stages. The proteins are successively broken down into proteoses, peptones, amino-acids, aromatic bodies such as indol, skatol, and phenol, and finally gases and elements. The first stages which result in peptone-production are often referred to as *digestion*, and in the latter stages as putrefaction proper. The process is exactly the same as that which occurs in the animal intestine when the proteins of the food are digested and, later, completely broken down. Among the gases produced are nitrogen (N), ammonia (NH_3), hydrogen sulphide (H_2S), sulphur dioxide (SO_2), and various oxides and hydrides of nitrogen and phosphorus. Of these, the sulphur compounds, which are invariably present, are extremely offensive, and hence the process of putrefaction is always malodorous. Many of these products of putrefaction have a high degree of toxicity to the body, and it is not quite certain which of them are the worst offenders in this respect. It is certain that there is produced somewhere about the peptone stage or below it a highly complex and highly poisonous group of bodies, which have been variously denominated toxins and ptomaines. It is possible that some of these may be of a simpler chemical nature, such as ammonium salts, a fact pointed out by Barger and Dale in connection with artificial culture of *B. œdematis maligni*, but our knowledge of the exact nature of these bodies is scanty. The proteolysis is due to the action of enzymes or ferments, which are formed in the secretion of certain intestinal glands in the case of food digestion, or formed by the action of certain proteolytic organisms on tissue in the case of most putrefactive processes.

In wounds putrefaction is produced both by aerobic and by anaerobic bacteria. It is seen in its most alarming form in cases of gas gangrene, where large masses of tissue die and become black and decomposed, with the evolution of vile odours and spread of gas under pressure upwards in the tissue planes. This condition is always associated with the action of anaerobes. The anaerobic bacteria of wounds fall into two main groups:

1. Saccharolytic or sugar-splitting group.
2. Proteolytic or protein-splitting group.

The second group, of which *B. sporogenes* (Metchnikoff) is the most prominent example, is, of course, particularly responsible for putrefaction, although most members of the first group are able to putrefy proteins also to some slight extent. Of the aerobic bacteria of wounds, the coliform group, especially *B. coli* of Ehrlich, is the most prone to produce putrefaction; but this is never of the extreme type produced by the gas bacilli.

In artificial culture media the putrefactive properties of certain bacteria are employed in their culture and differentiation. For example, egg media and meat media are blackened and decomposed by the proteolytic group of anaerobes—and these form suitable culture media for the growth of these organisms. Again, the action of certain coliform bacilli in producing indol from peptone in artificial culture is used in the group differentiation. In most of these protein-enriched media the gases of putrefaction are also produced in very considerable degree by proteolytic organisms.

Gas-Production by micro-organisms has been already dealt with in the remarks on *fermentation* and *putrefaction*. It is a phenomenon present, like the others, universally in Nature, and also occurs in wounds and in artificial culture media. The gases produced may be divided into two groups according to the mode of their production—(1) Those associated with fermentation and (2) those associated with putrefaction.

Class 1 are mainly carbon, hydrogen, and oxygen compounds, and are inodorous—*e.g.*, CO_2, CH_4, etc.

Class 2 are mainly nitrogen, hydrogen, sulphur, and oxygen compounds —*e.g.*, NH_3, NO_2, etc.

In connection with wounds the gases produced may be evolved locally, as in circumscribed putrid inflammatory areas, or may spread upwards in the tissues from the site of manufacture, as in spreading gas gangrene. In artificial culture media the gas produced in certain media is of the greatest assistance in determining the type and individuality of the organism concerned. This will be dealt with more fully in the remarks which follow on the various groups of organisms contained in wounds.

Other Biological Reactions

These constitute an ever-growing list as our knowledge of bacteriology increases. It is sufficient merely to mention here such examples as *liquefaction of gelatin*, *peptonisation of milk*, *acid and alkali production*, *and pig-*

ment production. These actions are due to the formation of enzymes by the *bacteria* during their growth.

Disease-production or **pathogenicity** is one of the greatest practical importance. It gives us the broad preliminary classification of all micro-organisms into two great divisions according to their action on man :

1. Pathogenic organisms.
2. Non-pathogenic organisms.

Class 1 alone is the concern of medical and surgical science. Of all the known micro-organisms, fortunately only a very limited number are pathogenic. There is no very well-defined boundary between the two divisions.

An organism which is ordinarily pathogenic may become non-pathogenic under certain conditions, such as prolonged growth at an unfavourable temperature, or in a culture medium containing unsuitable food, degree of moisture, or noxious substances—*e.g.*, antiseptics. A streptococcus or staphylococcus can be reduced from a powerful pathogenic agent to impotence by such means. The reverse condition is also occasionally seen, when a feebly or non-pathogenic organism, such as sarcinæ or *B. mesentericus*, can, by growth along with other strongly pathogenic agents (symbiosis), or by other means such as successive injection from animal to animal (passage), assume a distinctly pathogenic character. These, however, are " boundary line " cases and are somewhat exceptional. It is usually possible to assign an organism in its ordinary or habitual condition definitely to the pathogenic or non-pathogenic group.

A special type of pathogenicity which must be mentioned here occurs in the case of certain anaerobic bacteria, and particularly *B. perfringens*. These organisms are very severely pathogenic, but only under strictly limited conditions. Before the present war, *B. perfringens* was looked upon as practically a harmless saprophyte which could invade the body at or just before death, so few were the cases in which it was known to have produced definite pathogenic action during life, and this in spite of a very wide distribution in Nature. In present war wounds, however, the necessary conditions of its growth and development, restricted though they are, have only too frequently occurred, and in these wounds it has become, owing to the gas gangrene which it may produce, perhaps the most deadly pathogenic organism with which the war surgeon has to deal.

It is generally found that the pathogenic group grow best at a temperature above 25° C., and at an optimum temperature of 37 ° C.

Pathogenicity depends upon the production by the organisms of toxins or poisons. These are of two kinds—(1) intracellular or insoluble toxins and (2) extracellular or soluble toxins. The first are contained within the bodies of the bacilli, and do not diffuse out into the surrounding fluids. The extracellular toxins, on the other hand, are set free in such fluids during the growth of the organisms, and in the case of fluid culture

media can be obtained in solution by filtering the culture through porcelain, by which means the bodies of the bacilli are retained in the filter and the toxins pass into the filtrates.

In addition to these two classes of true bacterial toxins which appear to be direct products of the bacteria, there is another type of poisonous substance which is associated with the action of proteolytic bacteria. These are poisonous bodies derived from the actual proteins of the tissues as the latter become broken down by such bacteria. The best example is that of spreading gas gangrene in wounds, where great masses of tissue are destroyed, not only vitally, but also chemically. Here a great variety of products of disintegrated tissue protein are formed, and to some extent are absorbed into the general circulation. The toxæmia in such cases is a very profound one, and quite unlike that produced by the true bacterial exotoxins of the anaerobes (see chapter on "Gas Gangrene," p. 140). This class of poisonous substances appears to be a particularly deadly one.

The chemical nature of all these toxins is obscure, but most of them are known to be products of protein disintegration—toxalbumins and the like. They act by attaching themselves to the body cells, either locally or generally, or, as in the case of tetanus, to some special tissue cells, such as nerve cells, at a distance from the point of entry of the organisms.

Saprophytism and Parasitism.—These biological reactions constitute another broad line of cleavage in the world of micro-organisms, and they are of great importance from the human point of view. The distinction, again, is not a sharp one, for there is a very considerable intermediate zone of organisms which show both reactions in some degree.

A **saprophyte** is an organism which lives in Nature apart from other living organisms. A **parasite** is an organism which lives in or upon other living organisms.

A saprophyte is supposed to live upon the albumens of dead or inert tissue. The most outstanding example associated with war surgery has been already referred to—*B. perfringens*. This organism, which is derived from fæces, is habitually present in manure and manured soil, and may occur in any fæces-contaminated material. Under ordinary circumstances it invades the human tissues only after death. It has no power of growing upon healthy living tissue. If a pure culture be injected into the body of an animal, no result is usually produced, the bacilli being rapidly phagocyted and removed. In wounds, however, there are often produced masses of dead or greatly devitalised tissue, and on these the organism, by exerting its saprophytic function, also, in a sense, becomes parasitic upon the living body. It is most rare to find this action of *B. perfringens* exerted under any other circumstances than those occurring in war wounds.

A parasite may or may not exert a harmful action upon its host. A virulent streptococcus growing and spreading in the tissues or blood-stream is, of course, a most deadly parasite. There are, however, many organisms, such as skin cocci and intestinal cocci, bacilli, and spirilla, which live in habitual association with the body without producing under ordinary

circumstances any harmful result. Such organisms in reality live upon the dead products of the living body, and not at the expense of living tissue, although the association is a close one. They are also capable of leading a wholly saprophytic existence in Nature upon various organic materials apart from the living body.

There are, however, true parasites, such as *B. influenzæ*, meningococcus, etc., which die almost immediately after removal from the body, unless the conditions of their growth be artificially reproduced, as, for example, in cultures on a blood-serum medium kept at body temperature. This is, however, artificial saprophytism, and is not a phenomenon found in Nature.

Enough may have been said to point out the general distinction between saprophytes and parasites, and to indicate also that the difference, like that between the pathogenic and the non-pathogenic, is often merely relative.

Specific Bacteria of Wounds

The following list of bacteria and bacterial groups of organisms found in wounds is not complete, but comprises most of those which have been commonly found in all classes of wounds investigated both on the Western and Eastern areas of war. There is perhaps an infinite variety in the flora of wounds, comparable only to that of the human and animal intestine, from which the vast majority of wound bacteria are derived. In a series of cultures from wounds there often appear organisms which are difficult to assign even to a group, and in the various groups there occur individuals and subgroups which are atypical, and sometimes of a new and undescribed type. This applies especially, perhaps, to coliform organisms, diphtheroids, and diplococci. The following, however, includes the more common groups and individuals, and those whose specific action has been most completely worked out.

Aerobes :

Staphylococcus (several varieties).
Streptococcus " "
Enterococcus.
Pneumococcus.
Micrococcus tetragenus.
M. catarrhalis.
Sarcinæ.
Diplococci (various).

Bacilli:

B. coli communis.
Coliform bacilli (many varieties, including *B. proteus* and *B. Friedländer*).
Diphtheroid bacilli.
B. pyocyaneus.
B. influenzæ.
Subtilis mesentericus group.

Anaerobes:

Saccharolytic Group:

B. perfringens.
B. Von Hibler IX.
B. fallax (of Weinberg).
B. aerofœtidus (of Weinberg).
B. œdematiens (of Weinberg).

Proteolytic Group:

B. sporogenes (of Metchnikoff).
B. histolyticus (of Weinberg).
B. putrificus coli (of Bienstock).
B. cadaveris sporogenes (of Klein).
B. tetani (of Nikolaier).
B. fusiformis.
Spirillum Vincenti, etc.

It will be recognised from this list what a large majority are fæcal in origin, especially in the case of the anaerobes, which are practically all derived from the animal intestine. The conditions of life in the trenches, which are dealt with fully elsewhere, afford an all-sufficient explanation of this unfortunate fact, and from what has been said it will be seen that infection with fæcal organisms can hardly fail to accompany nearly all wounds of this war.

Cocci

Staphylococcus.—This group of cocci has representatives normally present in the healthy skin, as well as others which have a great tendency to adhere to the skin, and are found very commonly there in even the most cleanly persons. It is safe to say, therefore, that a staphylococcus of one kind or another invades every wound. A considerable number of varieties have been differentiated by various writers, but for practical purposes of pathogenicity these may be reduced to two:

1. *Staphylococcus pyogenes.*
2. *Staphylococcus epidermidis albus.*

The first of these is derived mainly from fæcal contamination, but also from the skin. The second is an habitual tenant of the normal skin.

1. STAPHYLOCOCCUS PYOGENES, when typical, produces a golden coloured pigment on agar, and is then called *Staphylococcus pyogenes aureus;* when atypical, it produces a white or merely a lemon-yellow pigment, and is then called *Staphylococcus pyogenes albus* and *Staphylococcus pyogenes citreus* respectively. These various types of *Staphylococcus pyogenes* are all morphologically indistinguishable. They are minute round cocci commonly 0·7 μ in diameter, and they divide in several planes, forming masses of individuals which resemble clusters of grapes. They

grow very readily on all the common media; on agar they form large opaque colonies ½ to 2 mm. in size. These colonies, according to the type producing them, are golden-white or lemon-coloured.

FIG. 6.—Twenty-four hours' culture of *Staphylococcus pyogenes aureus* on serum agar.

Relation to Wounds.—The action of *Staphylococcus pyogenes* in wounds is usually that of causing *localised suppuration.* It is seldom associated with spreading infection into neighbouring tissues, and is practically unknown to invade the blood-stream. Its virulence varies much, being generally

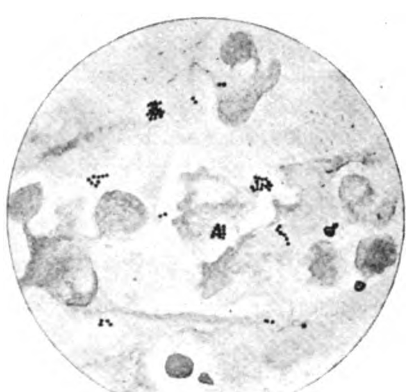


FIG. 7.—*Staphylococcus aureus.* A minute spherical organism measuring about 0·75 μ in diameter. It occurs in irregular groups, but also singly and in pairs. (× 1,000.)

highest in the *aureus* type. This type, which is also the most common, is at times a highly virulent organism, and produces a toxin which may be very powerful; but it remains localised and does not spread beyond the wound. The *albus* type is generally of intermediate virulence, and is

also of very common occurrence, and very often is present together with its near relative, the *Staphylococcus aureus*. *Staphylococcus pyogenes citreus* is of very rare occurrence, and an organism of low virulence.

2. Staphylococcus epidermidis albus is an habitual parasite of the skin, and is able to produce a mild local suppuration. It is of very feeble virulence. Its morphological and cultural characters are almost identical with those of *Staphylococcus pyogenes albus*.

The staphylococci are among the most resistant organisms in wounds, and usually persist in the wound during the course of sterilisation until surgical sterility has almost been attained—that is, until the number of organisms seen in film preparations made from the wounds is reduced to one or less per field. If the inhibitory action of the antiseptic be removed for a time, as, for example, by inefficiently applied dressings or by using unsuitable antiseptics, the staphylococci rapidly multiply, and within a day or two the count may reach fifty or more per field.

Any of the staphylococci may be associated with local suppurating foci or boils in the neighbourhood of wounds or on the skin generally. In the case of an army on active service, a great deal of disablement and loss of time is brought about by these suppurative skin conditions—boils, carbuncles, acne, furunculosis, folliculitis, impetigo, dermatitis, and the like, which, in the R.A.M.C., are grouped under the general heading of I.C.T. (inflammation of connective tissue). The causes are lack of facilities for cleanliness, unsuitable food, and debility from any cause, including, in the case of an army in the East, malaria and other tropical diseases. These conditions are almost always of staphylococcal origin, and they yield rapidly and completely to treatment by vaccines. Stock vaccines in large doses are sometimes useful in these conditions, but uncertain in their action, and never so strikingly successful as autogenous vaccines. The remarkable success attending the use of the latter in particular would suggest that there are a large variety of strains of the staphylococci, which, though morphologically and culturally indistinguishable, yet produce slightly dissimilar toxins, and therefore require a specific and dissimilar antitoxin for their neutralization.

Streptococcus.—This is perhaps the most important aerobic organism found in wounds. There are many varieties, which show a wide range of pathogenicity, as well as morphological and cultural differences. Different classifications of the streptococci have been proposed according to the different behaviour of the strains in certain cultural reactions. Schottmuller's classification is based on hæmolytic or non-hæmolytic action on blood-agar plates. The *Streptococcus pyogenes*, for example, when growing on such plates, produces colonies which hæmolyse the blood in the immediate neighbourhood, forming a distinct translucent halo around each colony. Certain other varieties produce no change in this respect. Andrews and Horder, on the other hand, have used fermentation tests with certain sugars as a standard of differentiation, and by this means have

been able to describe six different varieties. For practical purposes in connection with the surgery of wounds, we may regard streptococci as being present in two main varieties :

1. *Streptococcus pyogenes.*
2. *Streptococcus fæcalis.*

1. STREPTOCOCCUS PYOGENES is usually by far the more virulent. It is a parasitic micro-organism whose habitat is the surface of the body, the

FIG. 8.—Knee-joint synovial fluid. *Streptococcus pyogenes:* twenty-four hours' brain agar culture.

N.B.—The colonies are more distinct than a corresponding growth on agar.

natural orifices, and the intestine. It is commonly present in fæces, and gains access to wounds mainly from the skin and fæces-contaminated clothing.

Morphologically, the cocci are usually rather more ovoid in shape and rather larger than staphylococci, and they occur typically in longish chains (twenty to fifty members). A diplococcal arrangement is also very frequently seen both in films from wounds and in cultures.

FIG. 9.—*Streptococcus pyogenes.* (× 1,000.)

Culturally, growth occurs on all the ordinary media, but much more delicately than that of the staphylococcus. On agar the colonies are pin-point in size, translucent, with very slight central opacity, convex and shining by transmitted light, and greyish-white by reflected light. To obtain a copious growth of streptococcus, which is often desirable, for example, in the preparation of vaccines, it is well to use a medium specially enriched

in protein, such as serum agar, blood agar or trypagar. We have found brain agar to be equally good for this purpose, or even superior to those mentioned, and it has the additional advantage that it can be sterilised in the autoclave without deterioration. In the non-dustproof laboratories employed on active service, where it is difficult to keep serum and blood media sterile, this advantage is one of very great importance. *Milk* is a very suitable liquid culture medium for streptococcus, and is particularly suitable for culture of the organism from the blood or from inflammatory exudates, such as infected knee-joint synovial fluid. Streptococcus is a facultative anaerobe, and it often appears in anaerobic milk cultures in connection with the cultural investigation of the conditions just mentioned.

Relation to Wounds.—Streptococcus pyogenes is present in almost all wounds, and varies greatly in virulence. It is responsible for all degrees of inflammatory lesions, from indolent local suppuration to the most acute and fatal septicæmia. It is highly resistant to antiseptic measures when *in situ* in wounds, and is a difficult organism to eradicate. Indeed, in the course of the sterilisation of a wound by the Carrel-Dakin method it usually persists to the last, although its virulence becomes more and more diminished as the sterilisation progresses. In localised or chronic suppuration it is usually associated with other organisms, but it appears to exercise a more potent influence than most of the others. In preparing autogenous vaccines from wounds in order to raise the patient's immunity to his infection and to aid the healing process, whatever other organisms are found, a special effort should always be made to isolate streptococci and to make them the basis of the vaccine. The good results that follow the use of autogenous streptococcal vaccines bear out the truth of the well-known bacteriological findings that streptococcus is perhaps the most harmful of all the pyogenic organisms in wounds or any other suppurative foci.

Streptococcus pyogenes is, however, most typically associated with the more acute and spreading inflammations and with septicæmia. Such acute spreading conditions as acute cellulitis, osteomyelitis, and arthritis, in connection with wounds are almost always due to the action of *Streptococcus pyogenes*. A considerable number of cases can be recalled in which acute rapidly spreading osteomyelitis or cellulitis has supervened on a wound infection and has led to amputation. In such cases this organism can usually be isolated from the affected bone or œdematous and congested subcutaneous tissue at some inches above the position of the wound. *Delayed infection of the knee-joint*, which is a very serious inflammatory condition, has been found to be due in every case to *Streptococcus pyogenes*, and the usual path of infection in these cases has been a fissured fracture of femur or tibia from the site of the wound to the joint. A very fatal form of septicæmia following wounds, especially compound fractures or penetrating knee-joint wounds, is due to the *Streptococcus pyogenes* invading the blood-stream. It is always severe and usually fatal, and may run an acute or chronic course. The only effective treatment of such cases is by means

of heroic doses of an autogenous streptococcus vaccine. In a fair proportion of wound infections terminating fatally, whether as a result of secondary hæmorrhage or other condition, the blood appears to become invaded with streptococci alone or occasionally in combination with other organisms as a terminal ante-mortem event.

2. Streptococcus Fæcalis is a short-chained streptococcus occurring typically in pairs and in chains of four to eight members. In cultures its growth is not quite so delicate as *Streptococcus pyogenes*, the colonies on agar being rather larger and slightly more opaque. The sugar reactions of the two organisms are practically similar, acid-production without gas being produced in saccharose, lactose, salicin, and mannite. In addition, *Streptococcus fæcalis* produces clot in litmus milk and liquefies gelatine, while the pyogenes variety produces simply acid in litmus milk and has no action on gelatine.

Fig. 10.—*Staphylococcus aureus* and *Streptococcus fæcalis*: twenty four hours' culture from knee-joint fluid on brain agar.

N.B.—Both types of colony are larger than a corresponding growth on agar.

Streptococcus fæcalis is a constant inhabitant of the small intestine, and is very commonly isolated from fæces and fæces-contaminated material, such as sewage-polluted water.

Relation to Wounds.—In wounds the virulence of the organism varies, but is usually much less than that of *Streptococcus pyogenes*. It is a very common inhabitant of wounds, and is probably always present in connection with circumscribed putrid wounds, where it is associated with anaerobes and gas-gangrenous processes. It is much less frequently associated with acute spreading septic infection or with septicæmia than the *Streptococcus pyogenes*, but it undoubtedly does occasionally cause such acute infection. But of eight cases of streptococcal septicæmia complicating wounds which the authors investigated bacteriologically, six proved to be due to *Streptococcus pyogenes* and two to *Streptococcus fæcalis*. These two latter cases were of quite as severe a type as those due to the pyogenes variety. This may, however, be unusual, as other writers have more commonly found the septicæmia produced by it to be of moderate rather than of extreme severity.

Enterococcus.—This organism is conveniently considered along with the streptococci, as it is really a variant of the *Streptococcus fæcalis* group. It is still doubtful whether it deserves a separate designation, and until recently has not received it in English textbooks, although it has had for some years a literature of its own in French and German publications. Its very frequent occurrence in wounds has brought it into prominence during this war. Tissier found from his experience in Flanders that it was the most common organism found in wounds.

Its morphological and cultural characters are very similar to those of *Streptococcus fæcalis*. The chief points of difference culturally are that the enterococcus does not liquefy gelatine and does not clot milk, both of which are constant reactions of *Streptococcus fæcalis;* on the other hand, it causes acid-production in raffinose, a reaction which *Streptococcus fæcalis* fails to give. Otherwise the organisms appear to be identical.

Relation to Wounds.—The enterococcus is definitely pathogenic, but its virulence varies much with different strains. It is usually much less virulent than *Streptococcus pyogenes*. It is a pyogenic organism with a marked tendency to a local rather than a general inflammatory action. Its most typical and harmful effect in wounds is perhaps produced by enhancing organisms, such as *B. coli* and *B. perfringens*—in other words, by means of *symbiosis* with other bacteria. It is convenient to consider this question of symbiosis here, although it should be understood that it applies almost as much to the streptococci and other bacteria of wounds as it does to the enterococcus.

Symbiosis.—By symbiosis of bacteria we mean growth of two or more bacteria in close association in such a way that the growth of each is stimulated by the other. It is a widespread phenomenon in Nature, well known to agriculturalists by the example of nitrifying bacteria. These bacteria commonly attach themselves to the roots of leguminous plants, from which they draw their sustenance. In return they fix the nitrogen of the air, which becomes available to the plants as an essential and nourishing food constituent. In this way an active and progressive partnership is set up between plant and bacteria which results in mutual advantage.

A similar phenomenon occurs when different varieties of bacteria grow together in wounds. In combination they are often able to produce a much greater effect than the sum of all the singly produced effects.

This can be readily proved by cultural experiments and by animal injection. If we take a pure culture of an organism such as *B. influenzæ*, and another of an organism such as streptococcus, and make subcultures from each of these in two parallel strokes upon the surface of a sloped blood-agar tube, it is found that, by the association of the two organisms in the same tube, an unusually vigorous growth of each is obtained. When cultures of two organisms are injected together into laboratory animals, the reaction is enormously greater than that obtained by injection of the

same dose of each of them separately. Thus, a culture of the enterococcus injected into a guinea-pig produces varying effects according to its virulence, from a slight local inflammatory reaction to septicæmia within seven to fourteen days. Further, *B. perfringens* injected alone into a guinea-pig usually produces no effect unless the tissue at the site of injection be damaged ; even then it may be inert, but in some cases it produces a spreading gaseous œdema which may or may not be fatal. Now, on the other hand, when the enterococcus and *B. perfringens* are injected together under the same conditions, the fatal issue is practically certain to be produced within three days. Similarly, in wounds, by analogy and by observations on films and cultures made from a large series of wounded men, we can be sure that the combination or symbiosis of certain organisms, *ceteris paribus*, produces a much more severe or persistent inflammatory disturbance than that produced by the same organisms singly.

Enterococcus and Symbiosis.—The association of the enterococcus or streptococci and the gas-producing anaerobes is particularly deadly, in that thereby the anaerobes have a greatly increased chance of establishing their growth in the tissues. Whether the aerobes produce this stimulating effect on the growth of the anaerobes by means of toxin formation or of oxygen absorption is imperfectly understood. But it is now well established that, given dead or badly devitalised tissue such as is found in shell wounds, especially in fatigued subjects, and given infection with the enterococcus and *B. perfringens* or other set of pathogenic aerobes and anaerobes, and given also absence of oxygen in the depths of the wound, the conditions are ideal for the onset and rapid spread of gas gangrene. These conditions are so important because they are exactly those that obtain so commonly in war wounds, especially during rushes when the men are fatigued, and it is for this reason that gas gangrene has been so common in this war. Similarly in the case of tetanus. It has been found repeatedly that tetanus is more likely to supervene in connection with badly septic wounds than in connection with clean wounds, although the chances of contamination with *B. tetani* are equal in the two cases, and the reason for this is again that the presence of aerobes makes it more easy for *B. tetani* to grow and produce its toxins than when it has to rely upon its own powers of overcoming the resistance of the tissues and establishing its growth. In referring thus to tetanus we are aware that in civil life tetanus may follow upon a mere abrasion of the skin so slight as to be almost unobserved. But this is most unusual in connection with wounds, and may be regarded as the exception which proves the rule.

The enterococcus is one of the most common organisms of wounds, and, moreover, one which exerts its effect largely by symbiosis with other aerobes and with anaerobes. The latter action especially has been so deadly that it may be said that the chief pathogenic rôle of the enterococcus in this war has been as an adjuvant to *B. perfringens* in producing gas-infection. And what has been said in regard to the enterococcus applies

in greater or lesser degree also to other aerobes—*e.g.*, streptococcus, staphylococcus, *B. coli*, and the like.

Pneumococcus—*Morphology.*—The pneumococcus is well known as a capsulated, lanceolate diplococcus. It is rather larger than a streptococcus, measuring as a rule 1 to 1·2 μ in its greatest diameter. It occurs in this form in films from wounds, but in cultures it may form short chains of four and six members, and capsulation is indistinct. It then closely resembles morphologically a short-chained streptococcus. It is Gram-positive.

Isolation.—Its isolation from wounds is somewhat difficult. It can sometimes be isolated by washing the mucus or tissue or wound discharge in sterile water and plating out upon blood agar, brain agar, or trypagar. It is essential to use one of the protein-enriched culture media, and trypagar is especially suitable, as a neutral or slightly alkaline reaction in the culture medium is most favourable. The colonies are minute, transparent, and colourless, like drops of dew. They are scarcely visible to the naked eye. Under the microscope they appear distinctly granular and have a darker centre.

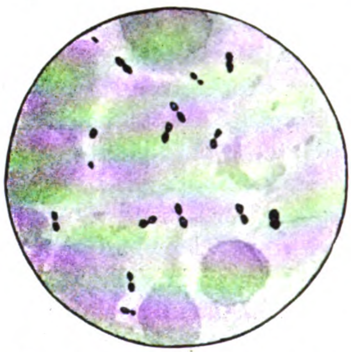


FIG. 11.—*Diplococcus pneumoniæ.* (× 1,000.)

The most certain method of isolation is to inoculate a white mouse with the material containing the organism. White mice are exceedingly susceptible to the pneumococcus, a virulent septicæmia being rapidly produced. The organisms can thus be readily obtained in pure culture from the heart's blood of the animal.

Relation to Wounds.—The pneumococcus is a normal inhabitant of the upper air-passages. It becomes a highly pathogenic organism when it invades certain mucous and serous surfaces—*e.g.*, the bronchioles, the peritoneum, the meninges, and the pleuræ. It causes local suppuration and severe toxæmia. The pus has often a characteristic flaky and mucoid appearance. In wounds the organism is of most common occurrence where the chest and air-passages are involved, hæmothorax and jaw cases being the two most frequent types of wounds which harbour it. It may be present, more rarely however, in wounds in any situation. In one case, for example, it was recovered by the authors from a wound of the hand, and in this wound the characteristic flaky mucoid pus was present. Fortunately, it appears very rarely to invade in wounds those structures, such as peritoneum and meninges, which are especially susceptible to its action. In a very large experience we cannot recall a single case of this.

The general action of pneumococcus in wounds is to assist the suppurative process, particularly in wounds of the respiratory passages.

Streptococcus mucosus is an organism closely allied to the pneumococcus, and occasionally found in wounds. It is a large capsulated, rounded cocco-bacillus, occurring in pairs, short chains, and occasionally in long chains. It is rather larger than the pneumococcus, measuring 1·25 to 1·75 μ in length and 0·5 to 0·75 μ in breadth. Each is surrounded by a relatively broad halo or capsule 1 to 3 μ in width. Like the pneumococcus, it is Gram-positive.

Its cultural characters resemble those of *Streptococcus pyogenes*, but the colonies are larger and have a bluish cast. They are thus easily distinguished from those of the pneumococcus. It grows most readily on the protein-enriched agar media, but is quite vigorous on ordinary agar.

The organism is a normal inhabitant of the human mouth. It is pathogenic to animals, and in man occurs in a variety of suppurative conditions. In wounds it is especially common where air-passages are involved, and occasionally is found also in wounds of other situations. It is a pathogenic organism, and its action in wounds is a localised suppurative one, without any tendency to cause spreading or generalised infection.

Micrococcus Tetragenus—*Morphology*.—This is a large encapsulated coccus, grouped in fours forming tetrads. The cocci measure 1 μ or slightly more in diameter, and are round, oval, or, more typically, kidney-shaped. The tetrad arrangement is very constant in wounds, although pairs are also often seen. It is Gram-positive.

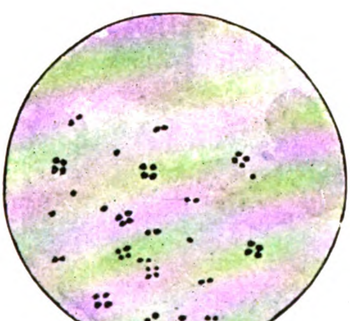


FIG. 12.—*Micrococcus tetragenus*. (× 1,000.)

Isolation.—This is easily accomplished by the ordinary plate method or by successive strokes on agar tubes. The organism grows very readily on all the ordinary media and at room temperature. On agar it forms spheric moist white colonies, which have a viscid and tenacious character, owing to the gelatinous nature of the sheaths of the cocci. The growth on agar is often confluent, forming a moist white layer.

Relation to Wounds.—*Micrococcus tetragenus* is a frequent tenant of the respiratory passages in health and disease, especially tubercular disease. It occurs most frequently in wounds of the respiratory passages, but it also occurs with a fair degree of regularity in wounds of other parts of the body, whither it may have been conveyed in droplets of saliva or saliva-contaminated material, such as clothing. It would seem that the knees of the trousers in soldiers are particularly liable to become infected, for the *M. tetragenus* is of not infrequent occurrence in penetrating wounds of the knee-joint. It is possible that the way in which food is eaten in the trenches may have some bearing on this fact, for food, part of which has

been in the mouth, is often placed upon the knees of the trousers. Out of fifty cases of penetrating wounds of the knee-joint investigated bacteriologically, the authors isolated it from eight. This gives a percentage of 16, and appears to be a relatively high proportion in comparison with the rate of frequency of its occurrence in wounds generally.

Micrococcus tetragenus is pathogenic to laboratory animals, especially to white mice, in which it causes a rapid septicæmia. In man it is one of the pathogenic organisms. In wounds it assists the suppurative process, and is not associated with spreading or general infection.

Micrococcus Catarrhalis—*Morphology.*—This is a relatively large ovoid *Gram-negative* diplococcus. It measures 1 to 2 μ in diameter. The

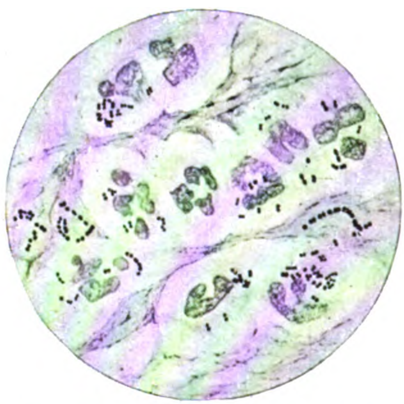


FIG. 13.—*Micrococcus catarrhalis* grown on blood agar. (× 1,000.)

Gram-negative staining differentiates it from most of the other common diplococci which occur in wounds.

Cultural Characters.—It grows very readily upon most media and at room temperature. On agar it forms large white colonies resembling those of *Staphylococcus albus.*

Relation to Wounds.—*Micrococcus catarrhalis* is an organism of the respiratory tract and conjunctiva, and occurs not infrequently in wounds of these structures. It is very slightly pathogenic to animals, and in man is typically associated with superficial inflammations of mucous membrane. Its action in wounds appears to be, in most cases, but a feeble suppurative one.

Sarcinæ—*Morphology.*—These are large rounded cocci which, in cultures, are grouped in little "cubes" or "packages" of eight or more members. They are closely allied to staphylococci, but morphologically they are larger, and show the characteristic "bale" or "package" arrangement; culturally they are of more coarse and vigorous growth. They are Gram-positive. They appear in films from wound exudate as large Gram-positive cocci in pairs or cubes.

Cultural Characters.—They grow readily on culture media at room temperature, forming large pigmented colonies, which after a day or two become umbilicated in the centre. The colonies are rather larger than those of staphylococcus. Some varieties produce a golden pigment, some a white, and some a lemon-yellow pigment. These varieties are called respectively *Sarcina aurea*, *Sarcina alba*, and *Sarcina lutea*. The last is much the commonest variety.

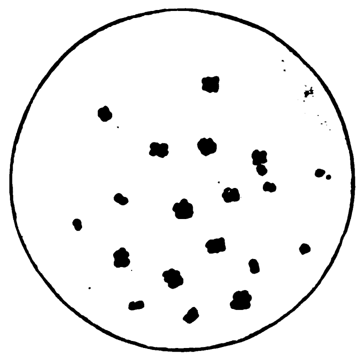


FIG. 14.—Sarcinæ. (× 1,000.)

Relation to Wounds.—Sarcinæ have their habitat in the gastro-intestinal tract. They are isolated very frequently from stomach contents, especially in a pathological dilated condition of the stomach associated with much fermentation. They are also of very common occurrence in fæces. They can be found frequently in superficial inflammations of the skin, impetigo and the like. They are slightly pathogenic, having very little action on the tissues when alone, but their action is much enhanced by the presence of other organisms. In wounds their chief action is to aid local suppurative and gangrenous processes by symbiosis with other aerobes and anaerobes. Their action is strictly localised.

GENERAL REVIEW OF THE PATHOGENIC COCCI

1. **Symbiosis with Anaerobes.**—Certain recent researches of Tissier (1916) throw considerable light upon the effect of the pyogenic cocci and other aerobes in influencing anaerobic activity. He showed both in wounds and by animal experimentation, that the aerobes whose chief action is localised, such as the enterococcus, *Staphylococcus epidermidis albus*, and sarcinæ, when associated with anaerobes, are jointly responsible for *circumscribed putrid wounds*. The spreading gangrenes, on the other hand, contain, in addition, true pyogenic organisms, such as *Staphylococcus pyogenes aureus* and *albus;* and in the most rapidly spreading, *Streptococcus pyogenes* is the associated aerobe. When mixed cultures of aerobes and anaerobes are injected into the damaged tissues of experimental animals, the result depends largely upon the nature of the aerobes injected. *The greater the tendency for the aerobe to spread in the general circulation, the more rapid is the onset of the anaerobic septicæmia.* Thus B. *perfringens* mixed with the enterococcus kills the guinea-pig in three days; mixed with *Staphylococcus pyogenes albus* in twenty-four hours; and with *Streptococcus pyogenes* in fifteen hours.

These findings are in complete agreement with our own observations on the organisms isolated by culture from a large series of wounds. The

usual effects of mixed aerobe and anaerobe infections are those outlined above, the severity being dependent mainly upon the aerobe present. Considering the extreme importance of the gangrenes, localised and spreading, in the wounds of this war, it is hardly too much to say that the relative importance of the various pyogenic cocci is mainly determined by the effect of their association with anaerobes. Further, the spreading gas gangrenes have been so much more dangerous to life and limb than the more localised that one might venture to place the associated aerobic pyogenic cocci in the following order with regard to their harmful action in wounds :

1. *Streptococcus pyogenes.*
2. *Streptococcus fæcalis.*
3. *Staphylococcus pyogenes aureus.*
4. *Staphylococcus pyogenes albus.*
5. Enterococcus.
6. *Staphylococcus epidermidis albus.*
7. Sarcinæ.

2. **Individual or Independent Pathogenic Action.**—Apart from the question of anaerobes, this order also roughly corresponds to their degree of pathogenic action when they exert their effect alone in ordinary inflammation suppuration. The most virulent inflammations are associated with *Streptococcus pyogenes.* A notable example is found in penetrating wounds of the knee-joint. If the aspirated synovial fluid from a series of infected knee-joints be examined, it will be found most constantly that, out of all those which contain aerobes only, the joints infected with *Streptococcus pyogenes* are by far the worst. The authors found that in this type of case it was usually hopeless to treat the joint by rest alone, but that it was necessary to open the joint early and apply vigorous active antiseptic measures. Even then the condition was very liable to progress to septicæmia. Similarly with the more chronic suppurations. It is here, again, the streptococci which are responsible for most of the damage. Cultures made from such wounds reveal their presence in practically every case, and the fact that autogenous streptococcal vaccines in these cases yield such good results indicates that the streptococcal toxin is the principal harmful agent.

The staphylococci, enterococcus, and sarcinæ, have on the whole been found to be more localised in their suppurative effects. The pneumococcus, *Streptococcus mucosus, Micrococci tetragenus* and *catarrhalis,* are in a class by themselves, as they are chiefly confined in their action to certain regions, and have affinities for mucous and serous surfaces.

3. **Diplococci.**—In smears made from wound exudate at various times during the course of the sterilisation of the wound, Gram-positive diplococci are perhaps seen more commonly than any other type of organism. In the majority of cases these are really streptococci, which very frequently assume the diplococcal arrangement when growing in wounds. Others

are staphylococci, pneumococci, enterococci, or sarcinæ. When these have all been excluded, however, there appears to remain a group about which we have little knowledge. They occur every now and then in cultures from wounds, usually as large Gram-positive diplococci, growing readily on the ordinary media. They sometimes exhibit polymorphism and resemble diphtheroid bacilli. Occasionally very small, delicate growths are obtained, resembling those of streptococcus, and the cocci themselves in such cases are smaller and more delicate. The arrangement of the cocci, however, is constantly diplococcal, and no appearance of chain-formation can be made out.

This group has not been sufficiently investigated, but it is very probable, judging by their cultural characteristics and by clinical considerations, that the first mentioned especially are of doubtful or low pathogenicity. At most they probably aid feebly the suppurative process.

Aerobic Bacilli

B. Coli Communis.—This bacillus, as the typical representative of fæcal contamination, must be expected to be a fairly frequent tenant of wounds. It has been thoroughly proved that *B. coli* is much more frequently present in wounds of the buttock and lower limbs than in any other situation. It seems to gain entrance to wounds mainly in the pieces of fæces-contaminated shirt, pants, and trousers, which are carried in with the missile. It can also be very easily introduced subsequently through lack of cleanliness or care in dressing wounds aseptically.

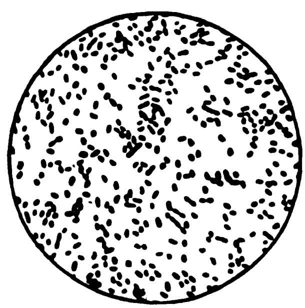


FIG. 15.—*Bacillus coli.* (× 1,000).

Morphology.—It is a short Gram-negative motile rod, measuring 1 to 3 μ in length. Its motility is due to a number of whip-like processes or flagellæ which are attached to its substance, and which, by their lashing in a fluid medium, cause movement of the bacillus.

Cultural Characteristics.—It is readily cultivated on all the ordinary media. On a twenty-four hours' agar slope the colonies are large, greyish-white, and semi-translucent. As they grow older, they enlarge and become more opaque. They are often confluent.

Litmus milk is rapidly acidified and coagulated. The litmus is first reddened, and later decolorised.

Sugar Reaction.—It has very active fermentative powers upon various sugars, and, in particular, produces acid and gas in lactose, glucose, galactose, lævulose, and mannite, while some varieties also produce acid and gas in saccharose. Gelatin is not liquefied.

Indol is formed from peptone in peptone-water media.

Relation to Wounds.—*B. coli* occurs as a saprophyte in great numbers in the human intestine, particularly in the colon, where it is concerned with fermentation and putrefaction of the intestinal contents. It oftens assumes a pathogenic rôle, particularly in suppurations connected with the intestine—*e.g.*, in appendicitis. It is also found occasionally in the blood, especially in cases where the wall of the gut has been injured, as in the dysenteries, and also in wounds of the intestine. Occasionally it invades the blood-stream from infected wounds involving bone, causing a severe septicæmia. In wounds its action depends upon the conditions present and the stage of the inflammatory process. In gangrenous wounds, where the sugar-splitting anaerobes have broken down the fermentable carbohydrates of the dead tissue, and where the putrefactive anaerobes are at work converting proteins into simpler products, *B. coli* is able to intervene at the peptone stage of proteolysis, forming indol and other aromatic compounds from these substances. It can therefore act in these wounds as one of the subsidiary proteolytic bacteria. In ordinary suppurative wounds, where there is no dead tissue to be destroyed and the interaction is between the bacteria and living tissue, neither its fermentative not its putrefactive properties are called into play. But there, by its severe toxic action and by symbiosis with other organisms, it becomes intensely pyogenic. In suppurations in bone, where venous channels are opened up, it occasionally gains access to the blood and gives rise to a septicæmia of moderate or considerable severity. It is at times found in the blood also as a terminal ante-mortem event in cases of septicæmia due to other organisms—*e.g.*, streptococcal septicæmia.

B. coli is not very resistant to hypochlorite treatment of wounds when thorough surgical exposure of the wound has been made and dead tissue eliminated. When the Carrel-Dakin treatment is used, and properly carried out it disappears rapidly (within a few days in most cases), preceded or accompanied by the disappearance of the anaerobic bacteria. When gangrenous tissue and sloughs, macroscopic and microscopic, have been dissolved away, and the sterilization process is actively continued, it seldom persists long in the wound. If it does, there is certain to be something wrong either with the preliminary excision of the wound or with the mode of application of the dressings. It is never one of the terminal organisms which remain in the wound when sterilisation is nearly complete —*e.g.*, when the bacterial count is less than three or four organisms per field. Its resistance in wounds approaching sterilisation appears, therefore, to be very much lower than that of the pyogenic cocci. On the other hand, when flavine is the antiseptic used, the resistance of *B. coli* in wounds is relatively much greater, and during flavine treatment it may be cultivated readily at a stage when no growth of the pyogenic cocci can be obtained.

Coliform Bacilli.—This is a large and interesting group of the bacterial flora of wounds. It includes several subgroups, such as the Proteus

group, the Friedländer group, and many varieties of bacilli resembling more or less closely *B. coli* at one end of the scale and *B. typhosus* at the other. The variety of organisms of this class found in wounds is perhaps as great as the variety of such organisms found in fæces. In making a series of cultures from wounds, one constantly finds organisms of this class which do not fall into any of the well-known subdivisions. Moreover, it frequently happens that, in a series of wounded men coming at the same time from the same part of the line and treated with the same conditions, similar strains of coliform bacilli are found with great regularity in the wounds. Whether these have been introduced at the time of the infliction of the wound or at a subsequent period it is impossible to say. The example may be quoted of a series of about fifty bomb wounds inflicted at one time and in one quarter during an air raid, and admitted to a base hospital. Eight of these wounds, of which six were wounds of the lower extremities, yielded on culture a coliform organism having the following salient characteristics :

The organism was a small, slowly motile, Gram-negative bacillus. It grew readily in large whitish, semi-translucent colonies on agar. Gelatin was not liquefied. It formed slight acid in glucose and in litmus milk, but did not ferment lactose, mannite, saccharose, maltose, or dulcite ; nor did it produce indol. The reactions resembled those of Shiga's bacillus of dysentery, but the growth on agar was much more profuse, resembling, indeed, that of *B. proteus*, the acid-production less, and no agglutination with anti-Shiga serum took place. Unfortunately, means were not available at the time for testing for pathogenicity.

A similar organism to this has been found with considerable regularity in a large series of wounds of all kinds, the lower extremities being the site of most frequent occurrence. On several occasions it was also found in the blood of wounded men where it appeared to be the cause of a remittent fever of seven to nine days' duration (*vide* " Septicæmia ").

B. Proteus Vulgaris is found occasionally in wounds, particularly in the same class and stage of wound that harbours *B. coli*. These two organisms are often present together in the same wound. *Morphologically* it is an *actively motile* Gram-negative bacillus of length 1·2 to 4 μ.

Cultural Characteristics.—It grows readily upon the ordinary media. Upon agar it forms a moist, thin, greyish, semi-transparent, rapidly extending layer. Single colonies are irregular in shape, owing to numerous offshoots from the periphery of the colony. So marked is this feature in some cases that the colony can be said to be in a condition of amœboid movement. *Gelatin is rapidly liquefied*, and this feature readily distinguishes the organism from most of the other coliform bacilli. *Milk* is coagulated.

Sugar Reactions.—Glucose and saccharose are fermented, with acid and gas production. It is a non-lactose fermenter. In most culture media it produces a characteristic and very disagreeable odour, and this is most

marked in media not containing sugar. In such media its putrefactive properties come into full play, and it produces the aromatic compounds skatol, indol, and phenol, as well as gases of putrefaction, from breaking down of the peptones.

Relation to wounds.—These reactions which are produced in culture media provide a clue to the action of the organism in Nature and in wounds. It is an organism of the large intestine, where it exerts a fermentative and putrefactive action on the intestinal contents. In any series of bacteriological examinations of fæces, *B. proteus* is very frequently found to be present. Both in the animal intestine and in wounds its action is very similar to that of *B. coli communis*, except that its putrefactive activity is somewhat greater. In gangrenous sloughing wounds it assists tissue lysis, and in all wounds it aids the suppurative process. Its duration in wounds and degree of resistance to hypochlorites, and to the antiseptic dyes, such as brilliant green, is practically the same as that of *B. coli*, which in most of these reactions is the type organism of the whole of this group of bacilli.

There is a subgroup of motile bacilli found in wounds which resemble *B. proteus* in type, but which show minor variations—*e.g.*, in cultural and especially in fermentative reactions. These are classed conveniently as the *proteus* subgroup of bacilli. For practical purposes, in wounds their reactions and effects may be considered to be identical.

B. Pneumoniæ (Friedländer) or the **Pneumo-Bacillus** is another aerobic intestinal coliform organism which not uncommonly appears in wounds, particularly in those involving any part of the respiratory tract.

Morphology.—It is a small, capsulated, non-motile, stout, Gram-negative bacillus. It is somewhat more elongated than the pneumococcus, and the capsule is of a similar breadth.

Cultural Characteristics.—It grows readily upon all the common media. On agar it produces a luxuriant whitish or slightly yellowish and very viscid layer of growth. This type of growth is common to a large number of the coliform organisms.

A *gelatine* stab culture is, however, characteristic. A rounded white mass is formed on the top of the gelatine, and a confluent growth along the needle-track. The result is the typical " nail-head " appearance.

The organism has great fermentative activity. It acidifies milk and produces acid and gas in nearly all the sugars, but does not form indol. Its putrefactive activity is therefore low or absent.

Pathogenicity.—It plays a part in suppurations of various kinds, particularly about the mouth, and it is the cause of acute lobular and lobar pneumonia in a relatively low percentage of cases.

Relation to Wounds.—The organism is found normally as a parasite in the respiratory and upper digestive tracts, and it also leads a saprophytic existence upon organic matter apart from the living body. The types of wound in which it most commonly occurs are those involving the respira-

tory apparatus, particularly hæmothorax and jaw cases. It appears to have a special selective inflammatory action on lung tissue. The authors have recovered it from pyæmic abscesses in the lung in most of the cases investigated. It occurs also occasionally in wounds of other parts of the body, particularly where there have been gross fæcal contamination and opportunities for the rapid multiplication of the organisms which have gained access to the wounds. Thus it is found occasionally in severe gangrenes or sloughing wounds. Its general action in wounds is fermentative, pyogenic, and toxic.

Other Coliform Bacilli.—A great variety of such organisms occur in wounds, and in making any large series of cultures from septic wounds, one not infrequently comes upon new types. One of these, which the authors isolated from a certain group of wounds, has been already described. Another one presenting slight differences from the latter organism may be referred to here.

This organism was isolated from 15 out of 200 open septic wounds from which cultivations were made. Every case from which it was isolated was a wound of the lower limb, and these wounds included penetrating knee-joint wounds, compound fractures, and flesh wounds.

The organism was a small, *motile*, Gram-negative bacillus, growing readily on agar in large whitish, moist, shining colonies. *Gelatine* was not liquefied.

Litmus milk was first acidified and later decolorised.

Acid was produced in *glucose* and *mannite*, but not in maltose, lactose, saccharose, or dulcite.

Peptone-Water.—General turbidity was produced. No indol was formed. We had no opportunity of submitting the organism to all the standard fermentative tests, but, so far as we were able to judge, the organism appeared to be identical with that described by Castellani under the name of *B. Kandiensis.*

The coliform bacilli of wounds approach more or less closely the type of *B. pneumoniæ* (Friedländer) or the type of *B. proteus*—that is, they are either mainly fermentative or mainly putrefactive. In our experience the former group is by far the commoner. Some, like *B. coli communis*, perform both saccharolytic and proteolytic functions in almost equal degree.

In general they are also pyogenic and toxic, and they exert these functions best in the presence of necrotic tissue in the wound. Their resistance in wounds to which the Carrel-Dakin method of treatment is applied is low, but under flavine treatment is relatively higher. On rare occasions they are capable of finding their way into the blood-stream and giving rise to a generalised infection or septicæmia of mild or moderate severity.

Diphtheroid Bacilli.—The occurrence of *B. diphtheriæ* (Klebs-Loeffler) has been definitely observed, though rarely, in certain wounds resulting from injuries in civil life. We are not aware, however, of any

published case in which this true diphtheria bacillus has been isolated from wounds of this war. It is possible that in the primary excision of wounds, which is now carried out within twenty-four to thirty-six hours of their infliction, the true diphtheria bacillus is removed or so diminished

FIG. 16.—Twenty-four hours' culture of a diphtheroid bacillus on brain agar. N.B.—This organism was isolated from an aspirated knee-joint synovial fluid.

in numbers that, in the face of the active antiseptic treatment which follows, it is unable to establish the typical recognisable form of the disease. That the disease is really present and unrecognised in any considerable number of cases is unlikely, since in that case the paralytic and paretic complications which are so characteristic and relatively common would be certain to give rise to comment.

There is, however, a group of bacilli, morphologically somewhat similar to the *B. diphtheriæ*, which commonly attack war wounds, and are found

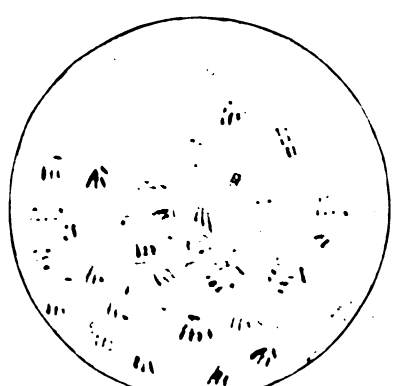


FIG. 17.—Diphtheroid bacillus. (× 1,500.)

both before and after excision of the wound. The primary infection of wounds in a large proportion of cases results in the growth of a greyish membranous exudation lining the track. One of the organisms which often occurs in large numbers in this membrane is Vincent's bacillus

(*B. fusiformis*). It is probable, however, that it is a mere saprophyte, living upon and breaking down the necrotic tissue. The other organisms found in the membrane are equally or more important, for they are often more toxic and provide the starting-point for the anaerobic activity. Among these extraneous organisms is the group of diphtheroid bacilli, which, indeed, by local toxic action assist in forming the membrane itself. Further, after excision of the wound, with its membranous lining, and while the reinfected surfaces are undergoing sterilisation, diphtheroid bacilli may still be found in the discharge, and, indeed, they are at times so persistent in the wound that they are still found along with the pyogenic cocci when the total number of organisms seen in films is low enough to admit of secondary suture being safely performed. The latter condition particularly applies to wounds which have parts difficult for the antiseptic solutions to penetrate. Diphtheroid bacilli are much less luxuriant in wounds treated by the Carrel-Dakin technique than in those treated by the older methods. It is this group of aerobes, perhaps more than any other, whose numbers and virulence in wounds appear to be so much diminished by the efficient application of the Carrel-Dakin treatment. Thus, in a large series of wounds undergoing this treatment the diphtheroids have been found to be of relatively uncommon occurrence, and have been in most cases confined to wounds of chest and jaw. Wounds of these regions are readily accessible to the diphtheroid bacilli, whose natural habitat is the buccal and respiratory mucous membranes. Such wounds, moreover, are often unsuitable for the application of the Carrel-Dakin technique which appears to be particularly inimical to them.

Morphology.—The type of organism is *B. diphtheriæ* (Klebs-Loeffler). This is a relatively small (1 to 6·5 μ), non-motile, Gram-positive bacillus. It has distinct granules in its protoplasm, which show different staining reactions from the body of the bacillus with certain stains—*e.g.*, Loeffler's methylene blue and Neisser's stains. These are known as metachromatic granules. Another and most characteristic feature is its pleomorphism, or variety in size and shape of the individuals in cultures. Thus, in a twenty-four hours' culture many of the organisms are larger than normal; some are spindle-shaped, some lancet-shaped, and many have large clubbed ends.

Cultural Characteristics.—It grows fairly well upon the ordinary media, but prefers blood serum. Growth is never profuse. It is purely aerobic.

Litmus milk is acidified.

Sugar Reactions.—Acid is produced in glucose and maltose and certain of the rarer sugars.

Indol is not formed from peptone.

Its fermentative action is therefore limited, and it has no putrefactive action at all.

Pathogenesis.—It produces several very powerful toxins, one of which is a powerful general poison, and another (neuro-toxin) has a selective poisonous action on certain motor nerves, such as those of the heart, the

palate, and ocular muscles. A condition of neuritis is produced in these nerves, with consequent paresis or paralysis of the muscles which they supply. The organism is powerfully pathogenic to the lower animals.

Relation to Wounds.—Its natural habitat is the human mouth, where it is parasitic in certain individuals ("carriers"). It occurs rarely in civil wounds, and when it does, renders the subject liable to all the complications of the disease diphtheria, with the exception, of course, of the usual respiratory complications. The wound is often a shallow one, and the granulations become covered with a typical diphtheritic pseudo-membrane, consisting of necrosed tissue cells and leucocytes embedded in a coagulated fibrinous matrix which has undergone hyaline degeneration. The process is, therefore, one of "coagulation necrosis." The bacilli are found in great numbers in the membrane. They remain localised, producing their toxins and causing a profound general toxæmia. True septicæmia seldom, if ever, occurs. In the wound the diphtheria bacillus is usually associated with pyogenic cocci, which gradually transform the membrane into a sloughy discharging mass.

In war wounds its presence has not, so far as we are aware, been noted. This is probably on account of the primary excision of wounds, which reduces the number of infecting organisms so considerably, and also because of the vigorous and continuous antiseptic measures which are applied to war wounds. The diphtheria bacillus is a pure aerobe, and establishes itself only where there is a free supply of oxygen. In wounds it is, therefore, always associated with the superficial parts, and these are the parts which in all systems of war wound treatment receive adequate supplies of antiseptic. The effect of such treatment appears to be completely inhibitory on the organism's growth and activity.

Diphtheroids.—The group of diphtheroid bacilli found in wounds are mostly unnamed, and show considerable variation in their reactions, but morphologically show a resemblance to the true diphtheria or pseudo-diphtheria bacilli. In some cases very small bacillary forms, closely resembling streptococci, are met with. They grow readily on the ordinary media, but seldom profusely. The colonies on agar are in most forms slightly larger and flatter than those of streptococci, and show a tendency to umbilication. Their fermentative reactions vary, but are seldom marked. Some do not produce acid at all in any of the commoner sugars, and others ferment a variety of them, with acid-production only. They do not form indol.

Their chief action in wounds appears to be locally toxic and symbiotic. In combination with other organisms, the growth of each is stimulated. Very rarely do they enter the blood-stream, but a few cases have been observed in which this has occurred, and the septicæmia produced has been of a very severe kind. One such case, which is described elsewhere, showed every sign of an imminent fatal result, but was treated in time with an autogenous vaccine, the result being entirely successful.

B. Pyocyaneus.—This organism has long been recognised as a tenant of suppurating wounds, whether of civil or military origin, and the appearance of the bluish-green pus which it produces is familiar to every surgeon. Its presence in wounds, unless due to direct infection from another *pyocyaneus*-containing wound, as frequently happens in a surgical ward, if the greatest precautions be not taken, is one more example of the fæcal origin of wound infections. *B. pyocyaneus* is a common saprophyte in fæces, manure, and fæces-contaminated water, and thence it is very easily transferred to the skin and mucous membranes, on which it may become parasitic. This process could hardly occur anywhere more readily than in the trenches in which our front-line troops live.

Morphology.—It is a short, slender, actively motile, Gram-negative bacillus (1 to 3 μ). It closely resembles microscopically a coliform organism, but is easily differentiated by its characteristic growth on culture media.

Cultural Characteristics.—It grows readily upon all the ordinary media. On *agar* a bright green growth develops along the line of inoculation, and in two or three days this green pigment, fluorescin, diffuses out into the culture medium, giving it its characteristic fluorescent appearance. If the culture be kept some days longer, this green pigment is replaced by a second blue one (pyocyanin), and the medium changes from bright green to deep blue, and later to dark blue, and, in some cases, to a deep reddish-brown colour.

Gelatin is liquefied, and the growth on the medium is green.

Relation to Wounds.—In wounds its action is not generally apparent until suppuration is well advanced, and then the characteristic bluish-green pus may appear. It is more usually associated with chronic suppurations and wounds in which sterilisation is delayed, as, for example, by the presence of necrotic bone or a foreign body. Its action is typically a local pyogenic one, although invasion of the blood-stream and general infection have, in rare cases, been reported.

This organism has, in the past, been a great bugbear in connection with sepsis of all kinds. When once it appeared in a discharging wound, it proved most difficult to eradicate by the older methods, and it tended to spread from case to case in a ward. No such trouble is experienced with this organism under the Carrel-Dakin system of treatment, efficiently carried out. Out of nearly 2,000 wounds observed from almost the start to the finish at a base hospital, and all except a few treated by the latter method, clinical evidence of infection by *B. pyocyaneus* has been observed in little more than a score of cases. Out of a series of cultures made at all stages of the suppurative process from 200 of the above wounds, all of which were severe and septic, *B. pyocyaneus* was grown not more than six times. Most surgeons will agree that an incidence-rate of *B. pyocyaneus* of 2 or 3 per cent. is something quite new in the history of grossly septic wounds. If the absence of *B. pyocyaneus* can be regarded as an index of rapid and efficient sterilisation of wounds in any large series—a point which will,

we think, be generally conceded—the evidence brought forward in connection with this series of cases is overwhelmingly in favour of the Carrel-Dakin method as compared with drainage-tube, salt-pack, and other older methods.

B. Influenzæ.—This small bacillus is found usually only in connection with wounds of the respiratory tract, and, in particular, in hæmothorax fluids. It is not an organism of common occurrence in wounds.

Morphology.—It is a very minute (0·5 μ in length), non-motile, Gram-negative, aerobic, pathogenic bacillus, and is one of the class of "hæmophilic" bacteria, or one which requires a medium containing blood for its artificial cultivation.

Cultural Characteristics.—It grows best upon glycerin blood agar, or on any of the protein-enriched media to which blood has been added. The colonies are minute, transparent, and colourless, like drops of dew. In culture media its symbiotic action is well demonstrated by growing it in the same tube with other organisms, when the growth becomes more copious.

Relation to Wounds.—In smears made from wound discharge containing the organism, the latter can be demonstrated by staining with weak carbol-fuchsin for half an hour. The bacillus can also be obtained in culture by plate methods with the above-mentioned media. Its action in wounds is not well understood. It has probably a symbiotic action with the pyogenic organisms, by which it indirectly aids the suppurative process. In addition, it is well known to produce a powerful intracellular toxin which acts, in particular, upon nervous tissue, and thus in wounds it is doubtless able to increase the general toxæmia resulting from the wound infection.

Subtilis Mesentericus Group.—This group of bacilli is not usually credited with any pathogenic action, but some of the members are frequently found in certain types of wound, and the group calls for some attention here.

In morphological and cultural characters they bear some resemblance to *B. anthracis*, and they are usually included among the anthracoid group of organisms. They are purely saprophytic, and are commonly found on dead organic matter in soil, hay, etc. They are sporing bacilli, and their spores are liable to be disseminated into the air. Thus they are very widespread, and may be considered to be present in the air universally, except where the most scrupulous precautions are taken to render a place dust-proof. In laboratory work, especially in improvised laboratories, constant measures of protection have to be taken to prevent contamination of culture media by these and other organisms gaining entrance from the air.

Morphology.—They are large, stout, spore-bearing bacilli which usually retain Gram's stain. Their morphology presents some points of difference. They are seldom less than 5 μ in length and 1 μ in breadth, but they may be as long as 10 or 12 μ. The ends are usually slightly rounded, but may be square or quite pointed, as often happens in the sporing individuals. They

spore readily, the spore being usually central, or slightly eccentric, but never terminal. They are often in long chains, but may be single or paired. Filamentous forms are common. In young cultures they are Gram-positive, but as the culture ages, many of the individuals may lose the power of retaining Gram's stain.

The smaller forms may resemble morphologically the group of diphtheroid bacilli. They are, however, usually stouter, and some at least of the individuals in a film are usually spore-bearing.

The other group for which they may be mistaken are the anaerobic gas-producing bacilli, but there they can be differentiated by their peculiar and profuse *aerobic* growth, by their comparative absence of fermentative activity as tested by the sugar reactions, and by their failure to clot litmus milk. No mistakes are likely to be made if these points are borne in mind.

Cultural Characteristics.—These organisms nearly all grow very readily and at room temperature on the ordinary media. On agar profuse growths are obtained. Some of these—*e.g.*, *B. mesentericus*—resemble the colonies of *B. anthracis*—large, greyish-white, dull, wrinkled colonies with irregular auriculate edges and tending to become confluent. Others form a moist, dirty white, shiny layer on the surface of the medium. They are all aerobes, but are able to grow also, to some slight extent, under anaerobic or partially anaerobic conditions.

Pathogenicity.—This is very slight or absent. When pure cultures are injected into animals, the only effect produced is a slight local reaction at the site of injection. The bacilli injected are rapidly phagocyted.

Relation to Wounds.—In wounds these organisms appear to be present in a variety of conditions. In a large series of cultures from wounds we have found them in the following types of wound :

1. *Where there is gross necrotic or gangrenous tissue*—*e.g.*, in the wound in in limbs amputated for massive and spreading gas gangrene. In these cases they are, of course, always associated with *B. perfringens* and other anaerobic gas-producing bacilli. Their occurrence in these wounds is frequent.

2. *Hæmothorax cases.*—They may be frequently isolated from samples of infected hæmothorax fluid, especially where the gas bacilli are also present. They are rarely present in such cases without accompanying anaerobes.

3. *Ordinary septic wounds treated by gauze dressings, and not by the Carrel-Dakin method.*—This was frequently observed in certain of our early cases, which were treated in a base hospital, before the Carrel-Dakin method of treatment could be instituted in every ward. These wounds included a variety of septic wounds, such as compound fractures, severe flesh wounds, amputation stumps, etc. They were all treated by eusol dressings. Another series of cases in which these organisms were found by culture were septic wounds which had been kept for some time at the casualty clearing station and treated by a variety of the older methods. On admission to the base hospital, before the Carrel-Dakin procedure

was commenced, it was not unusual to find this group of organisms in aerobic culture.

From a consideration of these findings it would appear that the subtilis mesentericus group of bacilli have a very restricted growth in wounds, especially where there is healthy living tissue, and where active and efficient antiseptic measures are carried out, as in the efficient application of the Carrel-Dakin method. On the other hand, the organisms appear to be able to establish themselves (1) where there is gross necrotic tissue and the presence of anaerobes ; (2) in types of wounds which do not admit of active antiseptic treatment, such as wounds involving the pleuræ ; and (3) in wounds which have received the less efficient antiseptic applications associated with older methods.

These findings would appear to suggest, among other points, a correlation between these organisms and the anaerobic gas bacilli as regards pathogenic action in wounds. This is in accordance with the available evidence derived from animal experiments. The point is more fully discussed in the chapter on "Gas Gangrene" (p. 140), where it is pointed out that injection of a culture of *B. mesentericus* along with *B. perfringens* into an animal is much more likely to be followed by a gaseous œdema than infection of the pure anaerobe. This seems to be due, in part, to the aerobe taking up the attention of the phagocytes, and in part, perhaps, to oxygen-absorption or some other factor which causes an increased growth of the anaerobe when the aerobe is in proximity. The latter is a fact which can be verified by growing anaerobe and aerobe side by side in the same tube of culture medium.

The evidence, therefore, goes to show that symbiosis with other bacteria, and with the anaerobic gas bacilli in particular, is the keynote of the pathogenic action of this group in wounds. Further, this pathogenic action, if any, appears to be easily disturbed, and tends to be exerted only in the absence of a healthy resistance on the part of the tissues, or of those aids to the vital tissue resistance which are applied by efficient modern methods of surgical and antiseptic treatment.

Anaerobic Bacilli

The anaerobic bacilli have been long known to exist in the wounds of civil life and in the wounds of war, but until this war began they were, except in a very small minority of cases, regarded as harmless saprophytes incapable of producing any serious disturbance in the living body. Malignant œdema was a condition which had been met with in a few scattered cases, and it was very imperfectly understood ; while any pathogenic action of *B. aerogenes capsulatus* in the healthy living body was a rarity which few had had the opportunity of observing. The great surprise came in 1914, when the awful results of spreading gas gangrene were seen on a large scale for the first time. Surgeons then gradually became aware that the con-

ditions under which anaerobic gas-producing bacilli live and multiply were being regularly reproduced for the first time in the history of wounds, and that this new and terrible complication of wounds had to be investigated and mastered. Those various conditions found in wounds and wounded men which make the growth of the gas bacilli possible are described fully in the chapter on "Gas Gangrene," and need not be elaborated here. It is sufficient to say that within the past three years or so the anaerobic gas-producing bacilli have assumed a position of importance as pathogenic agents which is altogether new in their history. It is therefore highly important for the surgeon to understand the nature and reactions of these organisms.

The identity and reactions of the various anaerobes found in wounds have not yet been fully worked out, and there is still a considerable degree of confusion on the subject. This is partly due to the erroneous and contradictory statements which were made in the pre-war literature on the anaerobes—a literature which was based on an experience infinitesimally small compared with that which has recently been gained. It was of course known that these organisms were of fæcal origin, and the reactions of a considerable number of them had been investigated. But the whole question was academic, and no practical classification was then possible.

It had been long recognised, however, that two principal anaerobes were concerned in the occasional gangrenous inflammations which were seen in civil life. These were *B. aerogenes capsulatus* (Welch and Nuttall) and *B. œdematis maligni* (Koch). An important biological distinction between these two organisms had, moreover, been noted—viz., that while the former was chiefly a carbohydrate fermenter and had little action on protein, the latter was, on the other hand, principally a protein digester, and had a very restricted range of action on carbohydrates. Other anaerobes had been described as gangrene-producing agents in a few scattered cases. The subject, however, was confused, and the mode of action and inter-relation of the various organisms responsible for gangrene-production was very imperfectly understood.

With a much fuller knowledge of the reactions of the various anaerobes which have been isolated from wounds, it was possible for Henry and others in France to suggest a practical classification of these organisms. This classification divides them into two main groups :

1. The saccharolytic or sugar-splitting group.
2. The proteolytic or protein-splitting group.

1. The Saccharolytic Group

The members of this group vigorously ferment carbohydrates, with production of acid and gas, and they have only a relatively slight action on protein.

B. perfringens.—The chief member of the group is one which has been described under a variety of names, and which is now almost universally known by the general name of *B. perfringens*. It is the same organism as the *B. aerogenes capsulatus* of English textbooks, and has also been described under a variety of other names—viz., *B. Welchii*, *B. perfringens* of Veillon and Zuber, and *B. phlegmonis emphysematosæ* of Fraenkel.

Morphology.—The organism is well known as a large, stout, Gram-positive, non-motile, capsulated bacillus. In most media it does not form spores, at least in young cultures, but in media containing a relatively small amount of carbohydrate—*e.g.*, blood serum—it appears to find the conditions unfavourable, and spores are formed. In films made direct from wounds, the organism has the morphology described, occurs singly

FIG. 18.—Method of culture of anaerobes.

Two Petri dishes are sealed together by means of putty or plasticine. A perforated diaphragm is interposed between them. In the lower dish is placed a solution of sodium pyrogallate, in the upper dish is the medium which has been inoculated with an anaerobic organism.

and in pairs, and does not show spores. In films made from cultures, however, the appearances vary according to the culture medium employed and the age of the culture. Thus in films made from a forty-eight hours' anaerobic culture on glucose agar, some of the forms are short and broad, almost square in outline, but longer forms predominate. The bacilli occur singly and in pairs or in very short chains of four and six bacilli. They are capsulated and Gram-positive, but Gram-negative and indifferent forms occur, some of the latter giving the appearance of Gram-positive granules on a Gram-negative background. No spores are formed on this medium.

Cultural Characteristics.—The organism is purely anaerobic. It grows readily upon the ordinary media with the evolution of gas, and especially

so when the medium is enriched by the addition of 0·5 per cent. of a sugar such as glucose. If a shake culture in glucose agar be made and incubated anaerobically, the gas-production is often so violent as to expel the cotton-wool plug and part of the medium from the tube. The colonies on agar

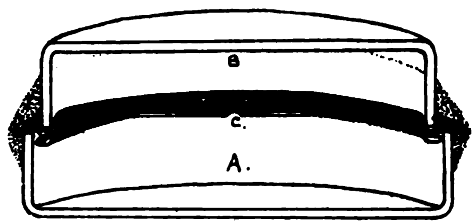


FIG. 19.—Section of apparatus for culture of anaerobes.
A, Chamber for solution of sodium pyrogallate ; *B*, chamber for culture medium ; *C*, perforation in the metallic diaphragm.

or glucose agar, after some days, grow to a large size (1 to 3 mm.). They are convex, glistening, moist, semi-translucent, gelatinous-looking, and viscid ; some of them show a central bubble of gas ; the margins become flattened and slightly wavy, showing a sort of ringed appearance. When they are picked off from the surface of the medium they are observed to be adhesive and viscid, owing to the thickness of the capsule with which the individual bacilli are surrounded.

Litmus Milk.—In this medium a characteristic phenomenon is produced, which is so useful in determining the presence of *B. perfringens*

FIG. 20.—Forty-eight hours' anaerobic culture of *B. perfringens* on agar.
Note the gas bubbles in the centre of the larger colonies.

in wounds that it may be called the *perfringens reaction*. It is very similar to the well-known reaction which used to be associated with *B. enteritidis sporogenes* (Klein), an organism which is possibly a mixed culture, for the reaction is given by *B. perfringens* in pure culture, and no spores are formed

by the latter organism in this medium. Further, *B. perfringens* can be recovered in pure culture by appropriate methods of subculture from the milk medium.

An attempt has been made to represent the reaction in colour (see Plate). When material containing *B. perfringens* is inoculated into a freshly sterilised litmus milk tube, and sterile paraffin wax or vaselin run on the top of the medium, the characteristic reaction is produced after from twelve to twenty-four hours' incubation. Fermentation of the milk-sugar takes place, with the production of a large amount of acid and gas. The milk becomes coagulated, and the clot is torn and contorted by the pressure of the gas. The paraffin wax is forced up the tube until it partially ejects the cotton-wool plug. The "honeycombed clot," at first decolorised, becomes tinged pink as air gains access to it. After a day or two it separates from the clear translucent acid fluid or whey. An odour of butyric acid is produced. The casein clot does not become digested unless one of the proteolytic group of organisms be also present.

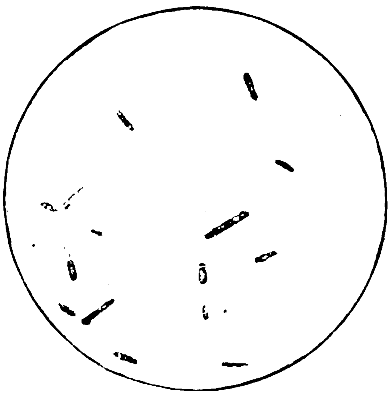
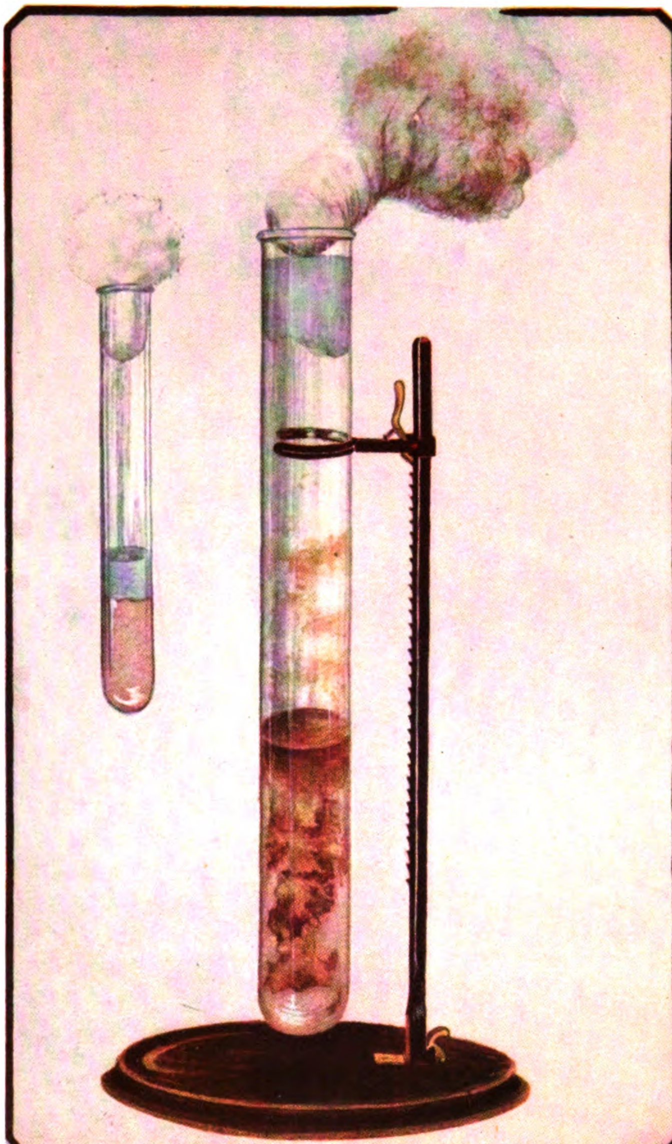


FIG. 21.—*B. perfringens*. (× 1,000.)

No spores are produced in this milk culture, and the culture dies out in some days, owing to the excessive acidity. Films made from such a culture show the typical large capsulated single or paired bacilli in great abundance, and they are Gram-positive.

A reaction of this vigour and with these characteristics may be taken as absolutely diagnostic of *B. perfringens*, as no other known organism reproduces it (Henry). If we consider *B. perfringens* as a group of closely allied organisms, all of which produce the above-described reaction, the reaction becomes definitive of the group. From the milk culture it cannot be isolated directly in pure culture, owing to the excessive acidity. If one or two subcultures be made, however, in an alkaline meat-glucose-broth medium, a growth of the organism can be readily obtained by plating out from the subculture on to glucose agar. From such a plate the typical gelatinous-looking colonies can be picked off and transferred to another medium until an absolutely pure culture is obtained.

PLATE I.



B. Perfringens growing in milk in a test tube. Note the formation of gas expelling the stopper, and the honeycombed appearance of the clot. This is the so-called Stormy Fermentation process in milk.

To face page 68.

Meat Medium.—This is a very suitable culture medium for such a strongly fermentative organism as *B. perfringens.* A good plan is to place the meat in an alkaline broth with 0·5 per cent. glucose added. In such a medium gas is formed vigorously, and the acid which is also produced turns the meat red, owing to hæmolysis of the contained hæmoglobin. Spores are produced after several days' incubation.

Four types of *B. perfringens* were differentiated by Symonds, and later confirmed by Henry. These differ in their reactions to glycerin and inulin.

Pathogenicity.—*B. perfringens* is a saprophyte in nature, and it becomes pathogenic only under a very strictly limited set of conditions. When a pure culture is injected into animals no effect is usually produced, and the bacilli are rapidly phagocyted unless the tissue at the site of injection be first damaged by some irritant. This can be done either by mechanical means or by the injection of a culture of an aerobe along with the anaerobe. Even such a harmless aerobe as *B. prodigiosus* may be sufficient for the purpose, and, in this case, presumably the action of the aerobe is that of diverting the attention of the phagocytes to itself and so allowing the anaerobe to establish itself. In a relatively small number of such cases gaseous œdema is thus produced, either localised to the site of injection or spreading throughout the body of the animal.

Again, in artificial culture *B. perfringens* has no power of growing in normal serum ; but if the serum be trypsinised it will grow vigorously. Similarly, it has the power of growing vigorously on serum removed from the body after death. This serves to explain why the organism so frequently invades the blood-stream after death, with production of gas throughout the organs. It appears also to be possible for *B. perfringens* to invade the blood-stream during life under certain conditions of diminution in bodily resistance. The relatively numerous recorded cases of metastatic gas gangrene are cases in point. Further, one remarkable case which we have observed seems to demonstrate that the presence of other organisms in the blood-stream may on rare occasions produce such a devitalisation of the blood that it becomes possible for *B. perfringens* to enter the blood-stream. In this particular case the active septicæmia agent was *Streptococcus pyogenes*, and all the symptoms were those of a lasting streptococcal septicæmia. The remarkable fact was that *B. perfringens* was present in the blood in association with the streptococcus for several weeks before death, and without producing any characteristic symptoms. It was isolated by blood culture on two occasions during life and at a two weeks' interval, and was also isolated after death. In this case the antitryptic power of the serum appears to have been so lowered by the presence of the streptococcus in the blood-stream that it became possible for the anaerobe to invade the circulation, where, however, it remained in a latent or non-active form.

Enough has been said here to indicate how feeble are the pathogenic powers of this bacillus in active living tissue. Exactly the same can be said of all the other gangrene-producing anaerobes.

The reactions of other organisms of the saccharolytic group of anaerobes are also shown in the accompanying table. It is seen that they ferment carbohydrates vigorously, but in varying degree. Their proteolytic action is relatively feeble, and varies in type and degree also. Some types of *B. perfringens* produce small quantities of amino-acids from peptone, while *B. aerofetidus*, on the other hand, is able to break down proteins as far as the aromatic stage, and there is consequently a disagreeable odour in cultures.

TABLE SHOWING FERMENTATION REACTIONS OF SACCHAROLYTIC GROUP OF ANAEROBES.*

	Dextrose.	Lævulose.	Maltose.	Saccharose.	Lactose.	Mannite.	Glycerin.	Inulin.	Salicin.	Amygdalin.	Glycogen.
B. Welchii I.	+	+	+	+	+	−	−	−	−	−	+
„ *II.*	+	+	+	+	+	−	−	+	−	−	+
„ *III.*	+	+	+	+	+	−	+	−	−	−	+
„ *IV.*	+	+	+	+	+	−	+	+	−	−	+
B. tertius	+	+	+	+	+	+	−	−	+	+	+
B. fallax	+	+	+	+	−	−	−	+	+	−	+
B. aerofetidus	+	+	+	−	+	−	−	−	+	−	+
B. œdematiens	+	+	+	−	−	−	−	−	−	−	−

These various anaerobes are of much less frequent occurrence in wounds than is *B. perfringens*, and their chief activity appears to be displayed as powerful but subsidiary fermentative agents. They supplement the action of *B. perfringens* in fermenting the glycogen of dead or devitalised muscle, and in initiating the process of gas-gangrene formation, with the production of a gaseous œdema. The pathology of gas gangrene and the action of the anaerobes in wounds is discussed is some detail in another chapter.

2. THE PROTEOLYTIC GROUP

These organisms digest protein vigorously, and have but feeble action on carbohydrates.

B. Sporogenes.—The type organism and chief member of the group is *B. sporogenes* of Metchnikoff. This is now believed to be the same organism as *B. œdematis maligni* of Koch, and the former name is to-day most generally adopted.

Morphology.—*B. sporogenes* is a fairly large bacillus (2 to 10 μ), rather more slender than *B. perfringens*, motile, Gram-negative, and contains a central oval spore of larger diameter than that of the bacillus, and giving a "barrel" shape to the organism as a whole.

* Henry, *British Medical Journal*, June 16, 1917.

Cultural Characteristics.—It is a strict anaerobe. It grows readily on ordinary media, with a limited amount of gas-formation and a foul odour.

Litmus milk is clotted and the casein digested.

Carbohydrate Reactions.—Acid and gas are produced in glucose, maltose, and lævulose only. Its fermentative powers are slight.

Protein Reactions.—Its most vigorous action is seen in media rich in protein. In a meat medium, it blackens the meat by putrefaction after several days. On Dorset's egg medium, perhaps, its most characteristic reaction is produced, as pointed out by Dean and Mouat.* It produces complete digestion, liquefaction, and blackening of this medium within three or four days. An offensive odour is produced, somewhat suggestive of Gorgonzola cheese. The digestion of protein is carried by this organism right to the ammonia stage.

Most of the other organisms of the proteolytic group have a similar but less vigorous action on protein. *B. histolyticus* of Weinberg, however, does not carry the putrefactive process beyond the amino-acid stage. Thus in wounds, just as in the fæcal contents of the colon, a considerable variety of fermentative and putrefactive organisms are provided by which dead and devitalised tissue or organic matter can be thoroughly and completely decomposed. The conditions under which this decomposition in wounds is brought about are dealt with elsewhere.

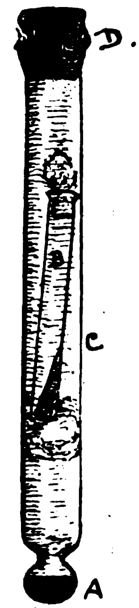


FIG. 22.—Apparatus for growth of anaerobes. *A*, Sodium pyrogallate solution ; *B*, tube containing culture of anaerobe ; *C*, outer glass tube sealed at *D*.

Incidence of Anaerobes in Wounds.—The most common anaerobe found in wounds is *B. perfringens*, and the next *B. sporogenes*. They are very frequently found to be present together. These organisms are found not only in gangrenous wounds, but also in a very large proportion of non-gangrenous wounds, where, presumably, they have been unable to exert their characteristic action. Thus, Henry, in France, found in 100 open septic wounds of all grades of severity that *B. perfringens* was present in two-thirds of the cases and *B. sporogenes* in half of them. In the vast majority of these wounds the anaerobic infection was mixed, the commonest combination being that of *B. perfringens* and *B. sporogenes*. The authors obtained substantially similar results in a series of nearly 100 severe wounds investigated for anaerobes in Salonika. About 75 per cent. were found to contain *B. perfringens* and 25 per cent. *B. sporogenes*. Of these wounds, clinical evidence of gas gangrene was obtained in only 35 per cent. It is evident, therefore, that gangrene-producing anaerobes

* P. 73.

are present at some stage in the vast majority of severe wounds; fortunately, only in a relatively small proportion of them are they able to establish themselves and produce gas gangrene.

B. Tetani of Nikolaier.—This most important organism belongs to the proteolytic group of anaerobes. It is found in wounds in a considerable proportion of cases in association with other anaerobes. It is not, however, a gas-gangrene producer, and its specialised function in causing tetanus is well known. The consideration of the whole of this important subject is relegated to another chapter.

APPENDIX TO CHAPTER IV

NOTES ON CULTURE MEDIA EMPLOYED IN BACTERIOLOGY OF WOUNDS

Liquid Media.

1. **Broth (Bouillon).**—

Extract of beef	... ...	2 grams.
Peptone albumin	... ...	10 ,,
Sodium chloride	... ...	5 ,,
Distilled water	... ...	1,000 c.c.

Boil till dissolved, titrate, add sufficient $\frac{N}{1}$ KOH to give a + 10 reaction, and filter when cold. Sterilise in the autoclave. Broth may also be made from fresh minced meat (1 pound to the litre of distilled water) in place of extract of beef.

2. **Trypsin Broth (Douglas).**—Take some fresh bullocks' (or horses') hearts, free from fat and vessels, mince the meat very finely, and weigh. To each ½ kilo add 1 litre of water, and make faintly alkaline to litmus with 20 per cent. KOH solution. Heat this slowly to 75° to 80° C. for five minutes. Cool to 37° C., and add 1 per cent. of liq. trypsinæ co. (Allen and Hanbury's) or of liq. pancreatis, and keep it at 37° C. for two and a half to three hours. When trypsinising is finished, test for peptone with $CuSO_4$ and KOH as below; then render slightly acid with glacial acetic acid and bring slowly to the boil for a quarter of an hour. Leave overnight in a cool place and siphon off the clear liquid in the morning. Make faintly alkaline to litmus, and sterilise in the autoclave at 118° C. for one hour on each of two days (if not to be used at once).

Biuret Reaction for Peptone.—Take 5 c.c. of broth, add 0·1 c.c. of 5 per cent. solution $CuSO_4$; mix, and then add 5 c.c. $\frac{N}{1}$ KOH. A true pink colour indicates that trypsinisation is sufficient, a bluish-purple shade that it is incomplete.

Liquor Pancreatis.—Mince a pancreas and weigh. Add an equal amount of absolute alcohol and shake. Add to this alcoholic suspension three times its weight of distilled water. Allow the mixture to stand for three days, shaking continuously. Filter, and add to the filtrate 1 c.c. strong HCl per litre. The acid preserves the strength of the solution for a very long time.

3. **Pea-Extract Trypsin Broth (Gordon).**—Take 100 grams of pea-flour (ordinary Pearce Duff's) and add 1 litre of distilled water with 100 grams of salt. Mix and steam for half an hour, stirring occasionally. Allow to settle and filter; then sterilise and label "Saline Pea Extract." (Filtration is slow, and it is best to leave the extract filtering overnight.) This pea-flour extract should preferably be freshly made for each batch of agar. Add to trypsin broth 5 per cent. of the saline pea extract, and sterilise in autoclave at 118° C. for one hour.

Trypsin broth is a more delicate medium than plain broth, and is well adapted for the pathogenic streptococci and diphtheroids and other organisms whose power of growth in artificial media is somewhat feeble. Pea-extract trypsin broth is a still richer medium used for the same purpose. Both of these broths are suitable fluid media for hæmoculture. They also form the basis of "trypagar."

4. **Egg Broth (Dean and Mouat).**—The white and yolk of one egg are thoroughly beaten up by vigorous shaking in a stout glass bottle containing a liberal supply of glass beads. Three hundred c.c. of distilled water are then added and the mixture thoroughly shaken. The bottle containing the mixture is placed in a water-bath, which is slowly brought to the boil. This temperature is maintained for half an hour. During the whole period of heating the bottle is constantly and violently shaken. The result is a loose porridge-like mass, consisting of finely divided particles of egg suspended in fluid. The medium is distributed in quantities of 50 to 100 c.c. in wide-mouthed bottles which are plugged and sterilised in the autoclave.

This medium is useful for growing anaerobes in primary fluid culture. A fluid medium containing suspended particles of animal matter is more suitable for most anaerobes than a clear solution, probably because natural saprophytic conditions are thus more closely simulated.

5. **Brain Broth.**—Obtain digest of brain tissue as in "brain agar" below. Mix equal parts of digested brain pulp and of ordinary broth; filter until filtrate shows only a slight turbidity (filtration is a slow process). Sterilise in the autoclave at 118° C. for one hour. This medium is an enriched broth suitable for the more delicately growing organisms.

An unfiltered brain broth containing particles of digested brain tissue in fine suspension may be used for the same purposes as egg broth.

6. **Glucose Meat Broth (Tarozzi).**—To 1 per cent. glucose broth pieces of sterile fresh meat are added as follows:

Kill a guinea-pig or other small animal. Immerse the carcass in boiling lysol for five minutes. Sear the skin with searing-irons, and make incisions through the seared areas with sterile instruments. Remove pieces of muscle aseptically, and place in tubes or flasks of glucose broth.

This is an excellent medium for anaerobes and suits *B. tetani* well. Growth of anaerobes occurs in this medium even when it is in contact with ordinary air. When the meat is sterilised by prolonged exposure to a

temperature of 100° C. or over, the medium loses this property. If sterilised meat is used, the culture must be put up under anaerobic conditions.

The saccharolytic anaerobes redden the meat and the proteolytic blacken it.

7. **Sugar Media for Fermentation Tests.**—

(*a*) *Peptone Water.*—

Peptone albumin	...	...	...	...	10 grams.
Sodium chloride	...	...	...	...	5 "
Distilled water	...	...	...	...	1,000 c.c.

Boil till dissolved, filter, tube, and sterilise.

Use 3 parts peptone water and 1 part (glucose-free) broth ; add 0·5 per cent. or 1 per cent. of the sugar to be tested, and litmus solution as an indicator. Neutralise with KOH solution. Insert a Durham's fermentation tube in each culture tube of the solution, and sterilise by steaming for one hour on each of three successive days in the Koch steriliser.

Media containing sugars must not be sterilised at high temperatures, owing to the liability of the sugar to decompose.

(*b*) *Hiss's Serum Water.*—

Ox serum ...	...	...	...	...	1 part.
Distilled water	...	...	...	...	3 parts.
Litmus solution	...	...	...	...	1 per cent.

Collect the serum as aseptically as possible, and add the sterile distilled water and litmus solution. Sterilise in a Koch steriliser at 100° C. on each of three successive days.

(*c*) *Solid Media.*—Sugars are sometimes added in the proportion of 0·5 per cent. or 1 per cent. to solid media such as agar or Loeffler's blood-serum medium. The characters of the colonies produced on the medium as well as the reaction to the sugar can thus be observed. An indicator such as litmus or neutral red (1 in 10,000 solution) is added.

For fermentation tests the peptone-water sugar media with Durham's fermentation tube are the most generally useful.

In the case of anaerobes growth is often more satisfactory in the serum-water media, and, in addition, the coagulation of the albumin in the medium by acid and the rupture of a clot by gas can be readily observed. This medium is also well adapted for fermentation tests with the more delicate anaerobes.

8. **Litmus Milk.**—Use fresh cow's milk. Boil and siphon off the milk from below the cream. Reject the cream. Add litmus solution, and acid or alkali sufficient to give the medium a neutral tint. Distribute in tubes, and sterilise as for sugar media.

Litmus Solution (*Kubel-Tiemann*).—Solid commercial litmus is digested with pure spirit at 30° C. till, on adding fresh alcohol, the latter becomes only of a light violet colour. A saturated solution of the residue is then made in distilled water and filtered. When this is diluted with a little

distilled water it is of a violet colour, which further dilution turns to a pure blue. To such a blue solution very weak sulphuric acid (made by adding 10 drops of dilute sulphuric acid to 200 c.c. water) is added till the blue colour changes to a wine red. Then the saturated solution of the dye is added till the blue colour returns.

Milk is a most useful medium for both aerobic and anaerobic cultures. The streptococcus grows well in it sometimes even when it fails to grow in primary culture on the solid media. It is a valuable fluid medium for hæmoculture. When covered with a layer of sterile paraffin (hard or soft) it forms a useful medium for anaerobes, particularly *B. perfringens*, the reaction of which in milk is characteristic (" perfringens reaction ").

Solid Media.

1. **Agar.**—Add 3 per cent. powdered agar-agar to plain broth. Autoclave, titrate, and filter as with " trypagar " below.

2. **Trypagar (Gordon).**—This medium was described by Gordon as suitable for the growth of the meningococcus.

Take a measured quantity of trypsin broth, add 3 per cent. of agar powder (or 2 per cent. of agar fibre), and 0·125 gram of calcium chloride per litre. Autoclave at 118° C. for three-quarters of an hour to dissolve the agar. Mix together in an iron saucepan, titrate with NKOH while boiling, using phenolphthalein as the indicator, and add the necessary amount of NKOH to give an absolutely neutral reaction (Gordon). We prefer a + 10 reaction when using this medium for the cultivation of the bacteria of wounds. Cool to 60° C., add white of egg (two to a litre), beaten up with the crushed shells. Autoclave again at 118° C. for seventy-five minutes (or in the steamer for two hours). Filter, and add to the filtrate 5 per cent. of the sterile pea extract, and sterilise inthe ordinary way.

Use trypagar with 2 per cent. sterile serum.

3. **Brain Agar.**—Mince some ox or horse brains and weigh. To each 7 pounds of brain pulp add 10 litres of distilled water and 0·4 per cent. sodium carbonate. Digest as for trypsin broth media. Add 3 per cent. powdered agar, autoclave, and titrate, and add sufficient NKOH to give a + 10 reaction to phenolphthalein. Tube, and sterilise in the autoclave at 118° C. for one hour.

4. **Blood Agar.**—It is best to secure blood from a large animal—*e.g.*, a horse. A Winchester bottle is fitted with a double-bored rubber stopper through which passes a long and short glass tube (see Fig. 23). The short tube is connected by rubber tubing to siphon filter (*a*), containing cotton-wool. The long glass tube is connected by rubber tubing to a trocar and cannula by means of an adapter. The trocar and cannula is wrapped in cotton-wool. The bottle contains 11 c.c. of 10 per cent. potassium oxalate for each litre of blood to be drawn off. The whole apparatus

is sterilised in the autoclave, and thereafter 1 or 2 litres of blood drawn off aseptically into the bottle. The cannula and adapter are now removed from the rubber tubing and replaced by a tapering glass nozzle (*b*), which passes through a bored stopper. The stopper fits into a tube containing carbolic acid solution 1 in 20, into which the glass nozzle slips. Any desired amount of blood may be siphoned off from this apparatus into agar which has been melted and cooled to a temperature of about 50° C. Siphonage is easily brought about by attaching a hand bulb-pump to the tube (*a*). When plain agar is used, 1 part of blood should be added to 2 parts of agar. When trypagar or brain agar is used, a much smaller amount of blood suffices. This is a most convenient and effective apparatus whereby blood may be collected and kept sterile in quantity without requiring the addition of preservatives, such as chloroform.

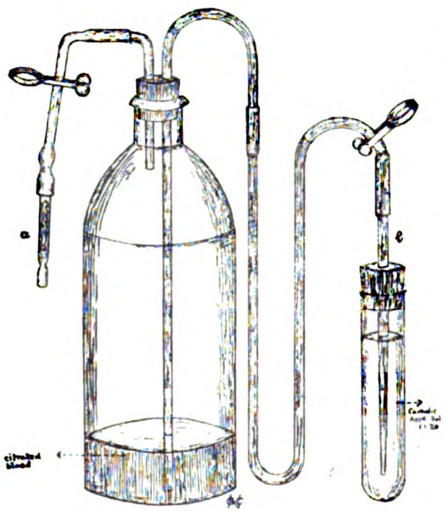


FIG. 23.—Method of collecting and storing sterile blood for culture media—*e.g.*, "blood agar."

Small quantities of sterile blood may be secured by sterilising the skin of the finger with spirit soap, ether, and iodine, pricking the finger, and taking up the blood in a sterile capillary pipette. A few drops of such blood added to a tube of melted trypagar or brain agar provides a most rich and delicate culture medium.

Agar is the most common solid medium in use in ordinary work. It is not sufficiently rich, however, to grow the more delicate organisms found in wounds—*e.g.*, pathogenic streptococci, pneumococci, etc. For these, and also for the purpose of securing luxuriant growths of all the organisms for the preparation of vaccines, trypagar and brain agar are used. Both are good media. Trypagar has the advantage of being nearly transparent and of permitting greater differentiation of the characters of the colonies of various organisms. It is therefore useful for primary cultures from material suspected to contain more than one organism. It has the disadvantage of requiring the addition of sterile serum to secure the best results. Burroughs and Wellcome's Normal Horse Serum No. 3 is quite good for this purpose, and is usually readily obtained. Brain agar has the great advantage (in dusty climates and laboratories) of being sterilisable in the autoclave without impairment of properties. It has the disadvantage of being opaque and of giving poor differentiation of char-

acter of colonies. It is therefore particularly useful for subcultures of known organisms, although it may be employed also for general use.

Blood-agar media are desirable for the cultivation of the "hæmophilic bacteria"—*e.g.*, *B. influenzæ*.

5. **Gelatin.**—Add 10 per cent. or 15 per cent. gelatin to plain broth. Melt by bringing slowly to the boil; titrate, filter, tube, and sterilise in the Koch steriliser at 100° C. on each of three successive days.

In hot climates it is advisable to use a mixture of agar and gelatin (0·75 per cent. powdered agar and gelatin). This mixture melts at about 28° C.

The chief use of gelatin media now is to test for the "liquefaction of gelatin" given by certain organisms. It is also used for special reactions—*e.g.*, *B. tetani*.

6. **Loeffler's Blood-Serum Medium.**—Three parts of calf's or lamb's blood serum are mixed with 1 part ordinary neutral peptone bouillon made from veal, with 1 per cent. of glucose added to it. The medium can be made from ox or sheep or horse serum and beef bouillon without its qualities being markedly impaired. The medium is distributed in quantities of 5 to 10 c.c. in test-tubes, sloped in a serum inspissator at a temperature of 80° C. for four hours on each of two successive days. This both coagulates and sterilises the medium.

This is a rich and conveniently prepared medium for organisms of feeble growth. Its disadvantages are that it is opaque and gives little differentiation of character of colonies. Minute colonies are not easily recognised on this medium. It is quite a suitable medium for *Streptococcus pyogenes* and diphtheroid bacilli, but it is not so generally useful as trypagar or brain agar.

7. **Dorset's Egg Medium.**—The contents of several eggs are well beaten, and one-third of the volume of normal saline is added and thoroughly mixed, the mixture being passed through muslin to remove air-bells. The fluid is then filled into tubes, and these are heated for four hours in the sloped position at 70° C. Before the inoculation of a tube, 2 drops of sterilised water are placed on the surface.

This is an excellent medium, suitable for all the organisms for which a rich protein medium is required. It has, however, the same disadvantages as Loeffler's blood-serum medium.

It is very well adapted for the cultivation of anaerobes, especially *B. sporogenes*, whose reaction on this medium is characteristic—viz., digestion, liquefaction, and blackening of the entire medium within three or four days.

NOTES ON SOME SIMPLE ANAEROBIC CULTURAL METHODS.

In bacteriological laboratories in the field it is essential to work with the minimum equipment consistent with efficiency, and hence, cultural methods requiring simple or readily improvised apparatus are generally

to be preferred. The following simple methods have given good results.

1. **Paraffin Seal (for Liquid Media).**—Some soft paraffin is melted and filled into tubes, which are then plugged and sterilised in the autoclave.

After inoculation of a liquid medium—*e.g.*, milk or broth—the sterile paraffin is run on the top of the medium to a depth of an inch, and the tube plugged and incubated. If more stringent anaerobic conditions are required, culture medium may be first heated to 100° C. for half an hour to expel oxygen, and a liquid paraffin seal run on the top before cooling. Inoculation of the medium is performed through the soft paraffin by means of a sterile capillary pipette.

The method is at best partially anaerobic. Its chief use is for anaerobic milk cultures, for which it is quite well adapted. The amount of gas formed from the medium can be roughly estimated by the amount of displacement of the paraffin seal up the tube.

2. **Use of Pyrogallate of Potassium.**—Buchner's anaerobic tube may be employed for maintaining or for keeping free from oxygen a sloped culture tube which is being used for separating anaerobes from mixtures. When several sloped cultures are being incubated anaerobically, a wide-mouthed, well-stoppered bottle or jar may be used. Dry pyrogallic acid is placed in the jar, and the culture tubes inserted. Potassium hydrate solution (109 grams solid caustic potash to 145 c.c. of water) is poured into the jar, and its mouth quickly stoppered and made air-tight by sealing the stopper with paraffin. The pyrogallate of potash solution so formed absorbs the oxygen in the air, and thus the cultures are kept in oxygen-free surroundings.

A pyrogallol-saturated plug may be used in a long culture tube for keeping a sloped culture partially anaerobic. The ordinary cotton-wool plug is pushed down into the tube, after inoculation of the medium. A little dry pyrogallic acid is placed on the top of the plug. A few drops of potassium hydrate solution are poured on, and a second plug is inserted into the mouth of the tube. This is pushed home, and melted paraffin run on to the top to prevent access of outside air.

These methods are often not strictly anaerobic, but are always useful for maintaining surface growths of anaerobes in subculture.

3. **Hydrogen Atmosphere.**—A vacuum is first produced in the anaerobic jar. A wide-mouthed bottle with a tight-fitting rubber stopper, carrying a bent glass tube with stopcock, makes quite a good anaerobic chamber. Bullock's apparatus (belljar on plate glass with double neck, bored stoppers, and stopcocks) is somewhat large, and requires considerable power to exhaust it of air. Any available pump may be used. If a water-tap with good pressure is available, a Geissher water-vacuum pump is very effective. A motor-bicycle pump with leather washer reversed answers the purpose very well.

Dry pyrogallic acid powder is first placed at the bottom of the jar.

The jar is then exhausted of air as far as possible, and hydrogen gas is run in from a Kipp's apparatus or Wolff's bottle for fifteen to twenty minutes. Lastly, potassium hydrate solution is run in. The pyrogallate of potash so formed absorbs any oxygen remaining in the jar, and turns black. When the air of the jar has previously been almost exhausted, as may occur when a Geissher pump is used, the pyrogallate solution may be barely darkened.

This method is somewhat laborious, but, provided an efficient pump be available, it gives an effective anaerobic chamber. It is recommended for the tube cultures. Anaerobic plates are best incubated by Henry's method (see below).

4. **Use of Palladium Chloride (McIntosh Canister).**—This is a recent and excellent device for securing absolute anaerobiosis. It depends on the fact that when hydrogen gas comes in contact with palladium chloride, the oxygen of the air is immediately and completely fixed by the latter.

The canister consists of a circular metal can with a flanged lid, which can be luted to the jar rim with plasticine, making an air-tight chamber. From the centre of the upper surface of the lid projects a metal nozzle with stopcock. From the centre of the lower surface there hangs suspended into the interior of the jar a flat, square wire gauze containing asbestos wool saturated with palladium chloride. This latter piece of apparatus is so placed immediately beneath the nozzle of the jar that when any gas, such as hydrogen, is allowed to pass into the jar through the nozzle, the gas must come in contact with the wool contained in the wire-gauze frame.

When the canister is to be used the culture tubes are placed inside the lid, firmly luted down. The air in the jar is partially exhausted by means of any convenient pump, and hydrogen gas is then passed into the jar. When the hydrogen comes in contact with the palladium chloride, the asbestos wool containing the latter glows with the intense oxidation which takes place, and all the remaining oxygen in the jar is thus fixed. Perfect anaerobic conditions can be secured by this device.

The disadvantages of the method are that neither the reaction, on which depends the production of anaerobic conditions, nor the growth of the cultures can be observed, and there is nothing to indicate how the cultures progress short of opening the can. To obviate errors, it is well to test the palladium with hydrogen in the open from time to time. Further, for plate cultures, in particular, the above disadvantages make the method in general inferior to that of Henry, described below.

5. **Henry's Method of Anaerobic Plate Culture.**—This is a modification of the capsule devised by McLeod for the incubation of each anaerobic culture plate separately. The principle is generally preferable to that of incubating plates in an anaerobic jar, since it is equally efficient; it permits of the colonies being readily observed during incubation.

In any military hospital or medical store there are found drugs in

powder (*e.g.*, boric acid) contained in cardboard cylinders which are provided with metal tops and bottoms. "The metal top consists of a circular disc or lid which, when pushed down, fits tightly into a supporting flange, the principle being one which is used extensively in trade for tins containing paints, enamels, etc. The combination of supporting flange and lid presents a circular groove or trench on both its upper and lower aspects, and so forms a suitable complying adjustment for the two halves of a Petri dish of suitable size." A 3½-inch Petri dish exactly fits into the grooves in the metal top of a boric acid cylinder.

Method of Use.—1. The grooves on both the upper and lower surfaces of the flange and lid are filled with plasticine (see Fig. 18, p. 66). One or two teaspoonfuls of pyrogallic acid in powder are placed in the lower half, *A*, of the Petri dish (see Fig. 19, p. 67), and the metal plate is pressed firmly down on to it, so that the edge of the dish is securely embedded in the lower plasticine-containing trench. Extra plasticine is added all round up to the level of the dotted line shown in the diagram, so as to make an absolutely air-tight lute.

2. The other half, *B*, of the Petri dish is sterilised in a larger Petri plate in the hot-air oven, filled up with a suitable amount of agar or agar-gelatin, and when cooled is inoculated.

3. Saturated caustic soda solution (10 c.c.) is poured through the hole *C* into the plate *A*, and then, as quickly as possible, the plate *B* in an inverted position is pressed firmly down into the upper trench and luted down with extra plasticine all round up to the level of the dotted line shown in the figure.

Organisms thus grow on agar surface in an air-tight box from which most of the available oxygen is absorbed by sodium pyrogallate. The smearing of the agar surface with alkaline egg medium at the time of incubation greatly facilitates growth. Where difficulty is experienced in getting growth by this method the organisms may be coaxed into giving good surface colonies by a preliminary passage through several subcultures in alkaline meat under paraffin.

We have found this method very efficient and very convenient.

CHAPTER V

WOUND INFECTION

For wounds of war, as for wounds of civil life, there are both predisposing and exciting causes of infection.

Predisposing Causes.—To realise fully the predisposing causes of wound infection it is necessary to have lived amongst, and under the same conditions as, the men in the trenches. It is a unique existence, and the work of the regimental medical officer is perhaps as interesting as any. He has ever to remember that one ounce of prevention is better than many pounds of cure, and it is up to him to keep the men of his battalion medically fit, as far as lies in his power, under all conditions.

What, then, are the predisposing causes of wound infection? They are the following:

1. Fatigue.
2. The conditions under which the soldier lives.
3. Climate.
4. The clothes the soldier is wearing.
5. Severe primary hæmorrhage.
6. Whether or not active fighting is in progress.
7. Constitutional or other diseases.

Each of the above-named causes calls for separate comment.

Fatigue.—Earlier in this war, when the man-power of the British Army was so different from what obtains to-day, the daily routine of the individual fighting man called for physical fitness and endurance of the highest quality. During the early months, when the enemy held superiority not only in numbers, but also in guns and ammunition, life as it then existed in the trenches often seemed wellnigh unbearable. Each day saw fresh destruction wrought on the habitat of the soldier by the regular, methodical, and thorough work of the enemy's artillery. Necessary repairs had to be carried out by night, usually under heavy machine-gun fire, as any breaches in the parapet were well marked down and sprayed intermittently with machine guns until dawn. Trenches, such as they were, contained a depth of liquid mud which would reach well to the knees of the average man and in some places halfway up the thighs. It was quite common for a soldier wading through this mud to leave his gum-boot

behind, it being impossible for him to drag his leg out by any other means. The mud, though constantly cleared out, would re-accumulate in a very short time. Trench grids constantly needed removal in order to get rid of the fluid débris from beneath them. Drainage trenches were under repair by day and night, owing to the destructive effect on them of enemy fire, and nightly repairs on communication trenches were necessary for the same reason.

Owing to the frequently inclement state of the weather, dug-outs which had not been blown in would fall in, whilst those which stil stood leaked so badly that they were usually inches deep in water and uninhabitable. Battalions or companies in the support line were constantly called upon to supply fatigue-parties for ration-carrying, or for carrying R.E. stores to the front line, whilst battalions which had left the trenches for a week's rest were often called upon to supply working-parties at night for the repair of communication trenches or other necessary fatigues. The nights were often wet and the men would return in the small hours of the morning soaked through. In addition to this, the men had always to be ready for an enemy attack or raid.

Though such conditions were borne cheerfully by officers and men alike, yet it was not surprising to find that fatigue was an important factor to be dealt with.

The following incidents impressed this point very strongly on the authors. They refer to the very rapid onset of rigor mortis in the case of men killed under these conditions.

On one occasion, after an enemy gas attack, while proceeding along a certain road, which was the shortest route after dark, to the front line, a soldier was seen in the kneeling posture, apparently taking aim with his rifle. As it was dark he was told to get up ; but as he failed to obey this order, an N.C.O. went up to him and pushed his shoulder. He fell over, and proved to be dead. He was quite stiff, rigor mortis being well established. This man could have been in this place a short time only, as a platoon had passed the spot just half an hour previously.

On the same night another soldier was seen standing propped up against the side of a communication trench which ran parallel to the same road. He was spoken to, but did not answer. On going up to him it was found that he was dead, and rigor mortis was well established. This man also could have been in this particular place for only a short time, or he would have been seen by a party of R.A.M.C. men who had an advanced dressing station but a few yards away, yet had not noticed him three-quarters of an hour previously.

Still one more remarkable incident. After the battle of ——, a number of wounded men had taken cover in a shell-hole in No Man's Land. They had their first field dressing applied, and were to have been brought in on the same evening after dark. The Germans counter-attacked that afternoon and retook their lost trenches, leaving No Man's Land as it existed

before the attack commenced. That night, owing to a heavy fusillade of rifle and machine-gun fire, it was impossible, despite several attempts, to recover all the wounded. At dawn this particular party of wounded men could still be seen in the shell-hole alive. After dark a stretcher-party went out to recover them, but found they were dead, although before darkness set in some were still sitting erect and were undoubtedly alive. Their bodies had to be left in order to rescue men who were still living. So life-like was the whole scene in this shell-hole even on the following dawn that it was called "The Tea-Party." One man was still holding his water-bottle, and appeared to be in the act of drinking.

Lastly, to emphasise this point, it was most noticeable how rapidly rigor mortis set in in the case of men killed outright in the trenches under the then-existing conditions.

There is no doubt that fatigue is a strong predisposing cause of trench ailments—*e.g.*, trench pyrexias, myalgias, trench feet, and the like—which, by lowering the general vitality, are predisposing causes of wound infection.

During the winter months the condition of the trenches in certain parts of the line hardly allowed of men standing upright, consequently, most of the day they had to crouch wherever they could get sufficient cover. Sleep under these conditions was impossible, as was rest of any kind, and with the necessary night work it is easy to understand the degree of fatigue that was bound to follow.

Convincing proof was that the percentage of men parading sick in the trenches varied inversely as the strength of the unit. The work of a battalion—*i.e.*, 1,000 men—must be carried on by whatever number remain; consequently, the fewer the numbers, the greater the work per individual to be done, and therefore the greater the fatigue.

Fatigue, as we at present know it, is due to an over-charging of the tissues with waste products of metabolism. The tissues so charged are temporarily toxæmic, and their resistance to infection is thereby lowered. The toxin is an acid substance related to lactic acid, and has received the name of sarcolactic acid. It is probable, however, that there are in addition other toxic bodies present. Experimentally, these toxic bodies can be washed away with normal saline solution, for if the muscle-nerve preparation of a frog be stimulated until no further contractions are obtainable, the muscle can again be made to respond by washing it with normal saline solution at a temperature of 37° C.

For further information on the subject the reader is referred to an interesting and instructive little work on Fatigue, written by Professor Mosso.

The Conditions under which the Soldier lives.—But few people outside those who have had actual experience realise the real conditions under which the soldier lives.

The existence of the soldier resolves itself into periods of time spent in trenches and periods of time in rest billets.

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THE CONDITIONS UNDER WHICH THE SOLDIER LIVES.—But few people outside those who have had actual experience realise the real conditions under which the soldier lives.

The existence of the soldier resolves itself into periods of time spent in trenches and periods of time in rest billets.

The Trenches.—The condition of the trenches is variable, and depends upon what part of the line a unit may be holding, and the time of the year. Certain parts of the line are notoriously bad, whilst others are good, and, again, artillery action is far more active in certain parts than in others. With a continual breakage of the parapet, demolition of the dug-outs, and trenches deep in mud, conditions are trying. It is here, however, that another more gruesome factor has to be reckoned with—namely, decomposing humanity. It was not at all uncommon to see the feet, head, or some other part of a corpse projecting out of the parados, or even to discover pieces of humanity in the mud of the trench bottom. In some places where a fatigue-party would start to open up a new communication trench the task had to be abandoned, owing to buried corpses which rendered the proposed work impossible.

In the same part of the line, at a time when it was difficult to get water, sumps had to be sunk. It was noticed that the sumps were filling at the expense of a marshy piece of ground not far distant. The water later, despite the fact that it was boiled, began to taste, and it was then noticed that at the bottom of the marshes were numerous unburied bodies of men who had fallen two or three months previously. Again, the bodies of men who had been buried out of necessity near the line were continually being unearthed by the enemy's fire; hence the mud both of the trenches and the ground about them was in one constant state of pollution. Trench latrines were frequently being hit, and by this means fæcal material was added to the already polluted trench mud.

Added to all this must be included weather conditions. During the winter months there was constant rain and inclement weather, and men were wet through. The advent of the long gum-boots certainly, to some extent, saved the feet and legs, but they were not always efficient, as the mud would often get in over the tops, especially if the men slipped off the duck-boards.

Despite this difficult existence, it was a noteworthy fact that, whatever the conditions, the soldier most unfailingly received his rations, his letters from home, and his tot of rum at stand-to in the morning. The rations were exceptional, and it was pleasing when doing an early round of the battered trenches to smell bacon cooking. Fresh meat, jam, and cigarettes, were always forthcoming daily, along with other comforts, and these never failed, despite the formidable barrages put up by the enemy's artillery. On the whole, therefore, life in the trenches was greatly compensated for by the way in which the necessary needs of the soldier were attended to.

Rest in Billets and Reserve Line.—Periods of rest in the reserve line were usually spent in billets in small deserted villages behind the firing-line. These villages were daily under shell fire, but the men who were not detailed for fatigues were able to sleep lying down at night, and the con-

ditions were generally better. In brief, these billets were a happy contrast to the trenches.

The Trench Rat.—Rats of a large coarse description are a constant pest in trenches, No Man's Land, and reserve billets. On the Somme they amounted to almost a plague. It was not uncommon to find one or two beneath the blanket when turning in for a sleep, and frequently they would run over men who were asleep. They fed on decomposing human remains, and on more than one occasion they have attacked a wounded man, especially if lying out; but the authors cannot record a case in which they have attacked a healthy man when asleep. One instance may be quoted of a man who was brought to the regimental aid-post with a large thigh wound complicated by a fracture of the femur. While attending to him, an urgent message came for the medical officer to go to the front line. On returning to the regimental aid-post to finish dressing the thigh wound, a large rat was found making a meal of the exposed tissues, and so loath was it to leave its prey that an orderly was able to kill it with a stick.

These rats would often become infected with disease, for on more than one occasion collections of their dead bodies were found at a time when no rat virus was in use. It is quite possible that they were poisoned by the foul food on which they preyed.

Constipation in Trenches.—Soldiers in trenches are notoriously constipated. This is probably a habit, because so many men have been hit while using the latrine. Many prefer to wait until they come out into rest billets, and then parade at the sick tent for an aperient.

Psychical Phenomena.—Life in trenches is associated, in a fair percentage of cases, with mental strain. Psychical phenomena are always more prominent after a successful bombardment by the enemy, from which casualties have resulted. It is not the actual bombardment that produces the effect so much as the event of a soldier seeing his next-door neighbour mutilated. Some of our bravest men have shown these symptoms, and have required four or five weeks' rest to recover, while a small percentage never seem to recover at all.

Climate.—Where hostilities are in progress in both Eastern and Western theatres, climate enters as a predisposing cause of wound infection. In the Western theatre rain and inclement weather have already been referred to, but in the Eastern theatre different conditions obtain. Here there are tropical diseases in the form of malaria, dysentery (both amœbic and bacillary), sand-fly fever, and the like, to deal with, besides the tropica heat.

Men coming to these parts for the first time, and under active service conditions, tolerate these diseases badly until acclimatised, and there is not the slightest doubt that their intervention produces a most deleterious effect on wounds.

The influence of these diseases on wounds is dealt with in Chapter XI., by Lieut.-Colonel L. F. Smith, C.M.G., R.A.M.C.

The Condition of the Clothes the Soldier is Wearing.—The khaki outfit of the soldier is too well known to need description here. During a period of rest out of trenches every provision is made for baths and a complete change of underclothing. This all takes place at the divisional baths, where a large stock of clean underclothing is kept. Each soldier before entering the baths strips and dumps his dirty underclothing. His trousers and tunic are taken and put through a Thresh disinfector while he bathes. On entering the baths he draws clean underclothing and socks. At the end of the day all dirty underclothing is put through the Thresh, sent to a laundry and washed, and again returned to the divisional baths. Blankets are similarly sterilised.

During a week's rest each soldier has probably two hot baths, with complete change of underclothing, and each time his outer clothes are sterilised.

Body Vermin.—Despite this, within twenty-four hours of return to trenches, these men are again infested with body vermin, although greasing the seams of the trousers with vermigelli or Oxford grease, and powdering the shirt with N.C.I. or Oxford powder, have been most conscientiously carried out under the supervision of the medical officer and the company officers.

Besides carrying disease, these pests, by their irritable action on the skin, prevent sleep and cause the men to scratch until septic abrasions of the skin result, and so are a potent predisposing cause of wound infection.

Again, in trenches clean clothes become rapidly soiled. The act of walking up a communication trench or a short distance along the front-line trench is quite sufficient to cake the outer clothes with mud, which, it should be remembered, is heavily polluted with decomposing humanity. In France and Flanders, where the farmers and peasants work the ground to the utmost extent, the soil is highly manured, not only with the excreta of cattle, but also with human excreta.

The soldier's underclothing, at first clean, rapidly becomes soiled with fæcal material. It is often a difficult task to impress on him the importance of wearing underpants. In the case of those men who do not wear them and escape observation, the khaki trousers become very fouled, and are consequently an important predisposing cause of wound infection, as it should always be borne in mind that a piece of clothing is invariably carried into the wound by the missile.

It has been suggested that all men before going into trenches or into action should have their clothes steeped in some antiseptic. To anybody who has had front-line experience it is obvious that this would be quite inadequate to sterilise the depth of mud and infective material that in a very few minutes collects in considerable thickness on the clothes, to say nothing of the effect that such antiseptics would have upon the skin.

Both for friend and foe alike, the very important problem of clothes, during the present war, as a very serious predisposing cause of wound infection, is still unsolved.

The Skin.—Closely allied to the problem of clothes is the condition of the skin. When once wet through with rain, the skin contains the same infection as the clothes, even after drying, and such infection remains in the dried sweat and hair. The man scratches himself owing to the presence of body vermin, and boils often result. Boils had of necessity to be treated in the line, unless a condition of cellulitis was established. Such a skin condition is a strong predisposing cause of wound infection.

Again, other conditions, such as scabies, entailing as it does, scratching and abrasions of skin, predispose to wound infection.

The Hair.—Another important item is the hair. Whenever a battalion is out at rest, every man should have his hair cut as short as possible. Long hair is a potent predisposing cause of infection in wounds of the head, as a portion of the hair is invariably carried in by the missile.

The Boots and Feet.—While out at rest, a foot inspection by the medical officer is most essential. Toe-nails should be cut short before the man goes to the divisional baths. Corns and callosities should be attended to by the battalion chiropodist. Deformities of the feet should be compensated by any simple device for altering the boots, and this can always be done by the battalion cobbler. Boots should be softened with neat's-foot oil or dubbin, especially if sores on the heel be present.

These latter remarks may seem trivial and unimportant, but it must be remembered that a deformity of the foot which might easily be remedied by some simple alteration of the boot, or even a sore heel, may rapidly induce fatigue in men on the march from rest billets to the trenches ; consequently, these men enter the trenches at a disadvantage.

It is careful attention to such small details as these that makes all the difference between keeping a man fit or unfit to carry on, and giving him a better chance to resist infection when the time comes.

Severe Primary Hæmorrhage and Shock.—When severe primary hæmorrhage occurs, the wounded man loses blood at a time when he can least afford it. His body is fatigued, and as a rule he is already suffering severely from shock. With hæmorrhage superadded on shock, he has to commence the battle against infection in a heavily handicapped condition.

It is too well known to require comment here that the main resisting force to infection lies in the blood ; hence a severe primary hæmorrhage is a serious early blow to the body defences. Every ounce of blood saved in the first few minutes following a wound is of paramount importance to the subsequent welfare of the wounded man, and this point should be most strongly impressed upon the mind of every stretcher-bearer. He should know the points of pressure for arrest of hæmorrhage from the large arteries, for a knowledge of these has time after time been the saving of many lives. Whenever the hæmorrhage is concealed, which may happen

in penetrating wounds of the abdomen or thorax, but little can be done towards procuring hæmostasis by pressure or other mechanical means. These latter cases are too often fatal, and if they do not die in the line they rarely get beyond a casualty clearing station.

Shock in the recently wounded man results from one or both of the following: (1) hæmorrhage; (2) reflex nervous action set up by injurious afferent impulses from the damaged tissue. The central feature of shock is due to a shortage of blood in the peripheral circulation, a condition which is produced by either of the above-mentioned causes. However produced, the symptoms are the same, but there is this important difference, that in the first case blood is irretrievably lost for some time to the individual, whereas in the second case the blood is still present in the body, but is stagnating in the distended veins of the abdomen and muscles. If these two conditions coexist to any considerable degree, the case is invariably fatal and death takes place on the battlefield. A combination of both of these factors constitutes the condition of intensified shock.

Another important difference between the above-mentioned two types of shock is that in the second case patients rally from the condition and respond well to treatment; but if hæmorrhage, whether visible or concealed, be the cause, response to treatment is exceedingly slow and infection is favoured.

It has been most striking how prolonged is the convalescence in the case of large infected wounds when severe hæmorrhage has occurred in the line. In these cases we have to reckon with the fact that there is the element of superadded reflex shock from the wound itself. This is especially so in the case of the extremities where amputation has of necessity been performed owing to hopeless mutilation of the limb. We have therefore in these cases varying degrees of intensified shock. Another noteworthy fact is the difficulty experienced in sterilising the wound of a patient who has suffered a severe primary hæmorrhage. Open amputations which have followed upon a severe primary hæmorrhage require the most active antiseptic treatment to combat infection, for if sepsis be allowed to exist in such amputation stumps, although the extent of such sepsis be small, secondary hæmorrhage is almost certain to follow.

Whether or not an Action is in Progress.—During the period that is known as the "quiet time" in the trenches, a wounded man can receive more individual attention from the regimental medical officer than he could were he wounded during an attack. It is possible under the former conditions for him to have the wound more thoroughly attended to at the regimental aid-post almost directly after he is wounded; he can be given hot drinks and a suitable dose of morphine, if necessary; he can be warmed and kept warm with plenty of blankets, and taken down by easy stages to the advanced dressing station or the field ambulance, where he again receives any further necessary treatment.

Hæmorrhage can be arrested at an early stage, and the wound dressed

with antiseptics. In short, shock and collapse can be greatly lessened just at a time when it is most urgent to deal with them. The journey to the casualty clearing station is not so hurried, and detention there can, if necessary, be longer. There is also no lying out after being wounded to be reckoned with.

Another very important point is that the regimental medical officer can furnish a few notes on the case which are invaluable to the surgeon at the casualty clearing station. For instance, in the case of paraplegia due to a wound of the spine, if the regimental medical officer can definitely state that there was an interval, however brief, after the wound was received, in which the wounded man could move his limbs, or in which sensation was present in an area of skin below the lesion, this is an invaluable piece of information to the surgeon who finds a complete paraplegia by the time the patient reaches the casualty clearing station. The same remarks also apply to head wounds, for it is important to know whether or not an interval of consciousness existed for any period, however short, after the infliction of the wound, and, if possible, it is highly important to know the early state of the pulse, respiration, and pupils. As a rule, this is quite possible during quiet times in the trenches.

When, however, an attack or an advance is in progress, a different state of affairs exists. A wounded man may have to lie some length of time, often hours, exposed to rain, cold, or heat, before he can be recovered. During this period he may be bleeding and suffering from severe shock and pain ; he may not be able to get drink of any kind or food, and such has been the case for periods varying from a few hours to days. He may, perchance, crawl into a shell-hole or a disused trench, for men with the most appalling wounds have been known to do this, and in this way many escape the notice of the stretcher-parties or salvage corps. There are instances known to the authors where wounded men in such a plight have been forced to eat grass, and have even drunk their own urine. One particular instance worthy of note is that of a man in —— Regiment, who was badly wounded in the chest and leg and lay out for eight days after the battle of ——. After the third day he managed to crawl amongst the dead who were lying out near by him, and to procure some of the rations they had carried with them. He had collected one or two water-bottles containing a little water, but when this was finished he had to resort to drinking his own urine. Eventually he was able to crawl back by stages, and enter our trenches after dark. Such conditions as these must strongly aid infection in the wounds of those few who survive them.

Again, when the number of wounded is large, the same initial individual attention cannot be given by the regimental medical officer. Men with wounds of the upper extremities, face, head, and chest who are not stunned can usually walk to the advanced dressing station, and on more than one occasion a man with his arm hanging on by only a few tendons has been seen walking down unaided to the advanced dressing station. Wounds of the

lower extremities involving fracture and abdominal injuries must be got down to the advanced dressing station and evacuated thence with the least possible delay, for it must be remembered that during an advance the wounded are an encumbrance, and their rapid evacuation from the scene of battle is highly desirable.

The journey to the advanced dressing station is not always a smooth one. It may be that this journey lies along a sinuous communication trench of considerable length, up which, on the one hand, are arriving reinforcements, and down which, on the other hand, are travelling the wounded who are able to walk. Under these conditions of congested traffic it is often necessary to carry the wounded men who cannot walk over the open under heavy shell fire and during this process the wounded man has often been hit again, to say nothing of the stretcher-bearers. It can well be realised that this part of the journey is a rough one, both for the wounded man and for those responsible for his transit; consequently, if the wound be severe and the limb imperfectly immobilised, further damage is suffered by the soft parts, shock is increased, and infection is thereby favoured.

On reaching the advanced dressing station, but little can be done for the more seriously wounded, owing to the number of other wounded requiring attention. They are put into motor ambulances, the more seriously wounded first, and are taken on at all speed to the casualty clearing station.

This entails a journey of about twelve miles, often over rough roads, which involves more shaking; hence by the time the clearing station is reached, the shock in the case of the badly wounded is intense, and the consequent degree of infection is very advanced.

Constitutional and Other Diseases.—During a war of such magnitude as the present many men were passed fit for active service who would never have been accepted in the Regular Service in pre-war times. The passing of recruits has necessarily been a somewhat hurried affair, and many unfit men have slipped past the examining medical officer. Thus it has been a common experience to send men out of the line suffering from such diseases as tabes dorsalis, chronic interstitial nephritis, pulmonary tuberculosis, and other diseases, all of which must act as strong predisposing causes to wound infection. Chronic valvular disease of the heart and arterio-sclerosis of varying degrees are not at all uncommon in men fighting in the line.

Another disease common in the army is chronic otorrhœa. Although this may not incapacitate a man as a fighter, yet it is an ever-living danger to a man wounded in the head anywhere in the neighbourhood of the ear.

Chronic inflammatory diseases of the respiratory annexes are for the same reason a fruitful source of infection of wounds in their neighbourhood, especially if the anterior basis cranii be involved.

One of the commonest diseases of all in the present-day soldier is dental caries—our remarks on this subject are set down in the succeeding chapter.

We need only state here that this is a potent cause of indigestion and malnutrition.

All these conditions are predisposing causes to infection, and all require prompt attention and treatment in order to give a wounded man his best and quickest chance of recovery.

There is one more point worthy of mention, though not strictly coming under this heading, and that is the case of the airman. Though it is not fully recognised, the life of the flying man in the present war is one which favours infection. One of the authors has treated many of these men for wounds, and has been struck by the fact that such wounds are remarkably prone to infection. A man flying in a rarefied atmosphere cannot rely on the normal atmospheric pressure directly after he is wounded; hence wounds received whilst flying at a high altitude bleed far more freely than wounds received on terra firma. Again, if the aeronaut can, notwithstanding his wound and loss of blood, land his machine safely, he suddenly descends from a rarefied atmosphere to a normal atmospheric pressure. This latter fact, coupled with the loss of blood, produces shock of a very intense degree, and an early operation performed on these men may often prove fatal. Under such conditions these wounds are very apt to become grossly infected. It should especially be noted that this is the one branch of the service above all, where it would be worth while to have a bath and put on sterilised clothes before starting a flight, for such gross infection as is seen in these cases can only come from the skin or the clothes. This point is referred to again in a later chapter.

The Nature of the Tissue Damage wrought by the Missile.—This has already been alluded to. Disrupted and stunned tissues, being in a very low condition of vitality, very soon die, and form excellent pabulum for the micro-organisms of disease. Severe bone comminution, damage done to one of the main arteries of a limb resulting in extensive hæmorrhage into the tissues of the part, and imperfectly immobilised fractures, are strong predisposing causes to infection.

Penetrating wounds, followed by œdema of the muscle of the part with herniation of the same through the wound of entry, completely occluding it, form an ideal condition for the life and proliferation of anaerobes.

Exciting Causes of Wound Infection are certain of the pathogenic bacteria. These have been dealt with in the preceding chapter. Certain points call for consideration here regarding modes of implantation of these bacteria into the wound. These especially concern—

(1) Foreign bodies.
(2) Flies.

Foreign Bodies may take the form of rifle bullets, shrapnel bullets, pieces of high-explosive or trench mortar shells, or of hand grenades, rifle grenades, bombs dropped by airmen, and the like. On the other hand, the foreign body may not be a piece of missile, but dirt, pieces of flint, or pieces of stone.

Whenever a piece of shell or other high explosive has penetrated the tissues in a clothed part, it has invariably carried in with it a piece of the soldier's clothing. The missile itself, after explosion of the shell, is probably sterilised by the heat generated. In the case of shrapnel the shell bursts in the air, and wounds of the soft parts caused by shrapnel balls are amongst the least infected, if the shrapnel ball prior to striking its victim is not distorted. In the case of the universal shell used by the Germans—*i.e.*, a combined shrapnel and high explosive—the shell-casing also breaks up, and a very different type of wound results, both as regards extent and degree of infection. In the case of high-explosive or percussion shells, the projectile strikes the ground prior to exploding; it may, indeed, if the ground be soft and muddy, penetrate a foot or more before exploding; consequently, the fragments into which the shell breaks up are befouled with dirt prior to striking their victims.

Wounds caused by rifle bullets or machine-gun bullets fired at a considerable distance, 500 yards or over, are perhaps the least serious from the point of view of infection. When fired at point-blank range, or at a range of 100 to 300 yards, a rifle-bullet wound can be as highly infected as any, as also can a wound caused by a ricochet bullet.

It must never be taken as a maxim that perforating rifle-bullet wounds, with a small hole of entry and exit, the so-called seton wounds, are practically harmless from an infection point of view. This might have been so in the South African campaign, but it has not obtained in the present war. One of us was doing duty as surgeon at a field ambulance during May, 1915, where all wounds were as a routine measure drained by means of rubber tubes. A great number of these wounds were caused by machine-gun bullets, and after the battle of —— almost all were highly infected by the time they reached the field ambulance.

Without a doubt the most important element in the case of infection is the piece of the man's clothing or other foreign bodies carried in by the missile, and not so much the missile itself. The missile brings about the necessary damage to the tissues, and the clothing, hair, dirty skin, or other foreign bodies, such as coins, pencils, paper, etc., that the soldier may be carrying with him, and which are driven into the tissues by the missile, are the main exciting cause of infection.

From what has been said before, it is evident that the clothes, skin, and hair of the soldier as he exists in the trenches, are teeming with most virulent bacteria, both aerobic and anaerobic, and these have been described in a previous chapter. Another point which strongly favours the theory that wound infection is directly brought about by the inclusion in the wound of pieces of clothing is the fact, that in a number of airmen who have been wounded whilst flying, the wounds have shown most virulent infection, with the presence of gas gangrene. In every case pieces of clothing have been removed from these wounds.

Wounds caused by high explosive of any kind show a higher degree of

infection, because the fragments are irregular and rough, and they therefore not only cause more damage and laceration of the tissues, but also carry in a bigger piece of infected clothing—that is, a larger dose of virulent organisms. The larger the piece of missile, the greater the damage to the tissues and the greater the piece of clothing carried in ; consequently, such wounds are more extensive both in degree of severity and infection. This has been most striking on more than one occasion, where troops have been caught in a barrage of heavy shells.

Flies.—When flies gain access to open wounds they may deposit thereon bacteria-infected material or larvæ, or both. The bacteria are conveyed on the legs and wings and in their stomachs and intestines. From the habits and mode of feeding of flies it is obvious that these bacteria are largely fæcal in origin. It is well known that flies feed readily on fæcal material, and this is always available in a battle area. From such material they convey the fæcal bacteria directly to the wound in three ways: (1) upon their legs and wings ; (2) by regurgitation of infected food material from their stomachs on to the surface of the wound ; and (3) by the deposition of their own excrement. Of these three methods of depositing bacteria upon the surface of a wound, it has been demonstrated that the deposit of the excrement of the fly is the most fruitful source of infection. In a well-fed fly the act of defæcation occurs every four and a half minutes.

Flies further affect wounds by the deposition of their larvæ in dead or dying tissue. Within a very short space of time maggots make their appearance in the wound in large numbers. Not many cases of maggot infection in wounds were seen prior to the Somme offensive in 1916, but during this battle the condition became common, and quite a number of these cases arrived at the casualty clearing stations. This infection occurs chiefly in men who have been wounded and have been lying out in the open with their wounds uncovered. There appear to be two types of maggots, a large and a small variety ; they exist in great numbers in wounds, and often by the time the clearing station is reached both blankets and stretcher contain many of them.

Maggot-infected wounds are extremely offensive to smell, yet the presence of these creatures in a wound has proved to be a not unmixed evil, for there is not the slightest doubt that they do in some way exert a strong inhibitory action on the growth of the more virulent bacteria. It is a noteworthy fact that gas gangrene and maggots do not exist together in the same wound, and that maggots survive at the expense of gas gangrene. Of the many maggot-infected wounds seen during the Somme fighting it was a most striking fact that these wounds did well. There was in these cases no gas gangrene and no tendency for the infection to spread locally.

Two cases particularly come to mind of extensive buttock wounds infected with gas gangrene, this type of wound then being of a notoriously fatal character. Both men were put out into the open air, the wounds

being protected by a cradle covered with fine muslin. Despite this precaution, the wounds became fly-blown and were soon alive with maggots. From the date of the appearance of the maggots both cases started to improve, further infection was arrested, and they were transferred to the base, having picked up in a marvellous way both locally and generally.

It is probable that these maggots digest and get rid of dead and necrotic tissue at a rapid rate, and so remove the pabulum necessary for the existence and multiplication of the more virulent bacteria present in the wound.

When all dead tissue has been removed the maggots disappear, and from what could be judged it would seem that they do not elect to live in living healthy tissues.

Two more instances were those of airmen who were hit while flying, and both had identical wounds, in that a large piece of the upper end of the tibia was completely blown away, leaving a large hole in the bone, which communicated in each case with the knee-joint. Both had suffered severe primary hæmorrhage.

One case, Second-Lieutenant W——, was operated upon soon after his injury, and suffered severe post-operative shock. His wound was grossly infected, and contained *B. perfringens* and *Streptococcus fæcalis*. The knee-joint recovered, but he is still unable to walk, and sequestration is slow and going on five months after the injury.

The second case, Second-Lieutenant D——, with an absolutely identical injury, had his wound full of maggots on admission. In twenty-four hours after admission the maggots had done their work, and were washed out of the wound with saline. The wound was sterilised by the Carrel-Dakin method, and sewn up over the hole in the bone. The wound healed, with the exception of a small piece of skin which gave way over the hole in the bone, the knee-joint entirely recovered, and he was able to put his full weight on the limb and to walk six weeks after the injury. This is a striking contrast.

Too many of such cases have been seen to be put down as coincidences, and it is, we think, not going too far to suggest that fly-blown wounds should be left until the maggots have removed all dead tissue present. Whether or not these creatures might not be useful as a means of treating extensive gangrenous wounds in the early stages is a point to be settled; for, horrible as the idea may at first seem, yet these maggot-infected wounds could not be any more offensive than similar wounds that were treated with the salt-pack.

CHAPTER VI

WOUND INFECTION (*Continued*)

THE general pathological processes underlying the phenomena of infection in wounds have long been familiar to the surgeon. The source of wound infection is, of course, the activity of the bacteria which are introduced into wounds. The *local effects*, such as *inflammation*, *suppuration*, *necrosis*, *autolysis*, *gangrene*, and *gas production;* the general effects, such as *toxæmia*, *septicæmia*, and *pyæmia;* and the *local* and *general bodily defences*, exerted by means of *phagocytosis*, and by the *production* of *anti-bodies in the serum*, all need no systematic description here. They are matters of common surgical knowledge, and have been described in standard textbooks many times. There are, however, certain special features in these phenomena of wound infection which have particular application to the wounds of this war, and these will form the subject-matter of the present chapter. Many of the pathological processes already known have now acquired a new meaning and interest.

The Local Infection and Local Tissue Response

I. INTRODUCTION OF ORGANISMS INTO WOUNDS

It has been shown elsewhere that the pathogenic micro-organisms which gain access to wounds do so in three chief ways: (1) in the piece of clothing which is invariably forced by the missile into every wound involving a clothed part of the body; (2) in particles of soil similarly carried in or subsequently introduced into the wound; and (3) from the skin at the orifice of the wound.

Enough has already been said to make it clear that under the present conditions of warfare these three sources of infection can hardly fail to be contaminated with fæcal matter, and this is the reason that the bacteria of wounds are mainly fæcal in origin. With regard to (2), the soil of Belgium, France, and Serbia, as well as other areas of the war, is all more or less highly manured, and under the conditions of trench warfare it receives constant additions in fæcal organisms from the excreta of men and horses of the opposing armies, and from the decomposing human and animal remains of the killed. This fresh contamination, which goes on daily increasing, is at its greatest in the firing-line,

in the very soil which is constantly being churned up by shell fire, and it is the contaminated particles of this soil which gain access to wounds along with shell fragments. With regard to (3), it has been related how difficult it is for the men in the front-line trenches to maintain even a low standard of cleanliness, and it is evident, from the conditions which exist, that the skin of these soldiers, especially about the buttocks, thighs, and hands, must constantly be polluted with the bacteria of fæces. So far, then, as these two modes of introduction of organisms into wounds are concerned, it is obvious that no measures which might be taken to reduce the danger of infection are at all likely to be efficient or even practicable under the conditions of front-line warfare.

With regard to (1), which is obviously by far the most important mode of conveyance of infective material, owing to the necessarily foul condition of the clothing of the men in the trenches, it has been suggested that something might possibly be done to keep the clothing sterile by the application of disinfectants. The idea arose from certain bacteriological investigations which seemed to show that if pieces of ordinary clothing (containing numerous organisms as they do) were saturated with a 5 per cent. solution of cresol and allowed to dry, they would remain sufficiently impregnated with the antiseptic during a month of ordinary wear to prevent or inhibit the growth of any organisms which might survive in them. In spite of the obvious difficulty, and indeed impracticability (for the method was actually tried on a small scale without success), of carrying out this procedure in the case of front-line units, a few simple cultural experiments were made by one of us in order to test the bacteriological findings. The results of the first experiments were so entirely negative that no further series of experiments was carried out. These experiments were briefly as follows :

1. The test pieces of clothing were obtained from an ordinary khaki uniform greatcoat and tunic worn by a soldier. The strengths of cresol tested were 2 per cent. and 5 per cent. solutions. The culture media used were *agar*, *milk*, and *broth*, the first being put up aerobically and the others anaerobically. Two procedures were used :

(*a*) Two test pieces of clothing were taken ; one was soaked in 2 per cent. cresol solution and the other in 5 per cent. cresol solution for one hour. They were allowed to drip dry, and left lying about in a dusty place for one week. Aerobic and anaerobic cultures were then made. *All these cultures yielded a copious growth of organisms.*

(*b*) Two test pieces of clothing were treated as above, but twenty-four hours before inoculation of the media they were smeared lightly with a thin fæcal emulsion, allowed to dry, and to lie about until the cultures were made. *All these cultures yielded profuse growths of organisms, and also abundant gas-production, in the agar shake and the milk cultures.*

2. The test piece of clothing was a piece of the underclothing (pants) of an officer. The garment was washed in 5 per cent cresol and worn

for seven days. Cultures were then made as above. *All these cultures yielded copious growths of organisms, and there was, in addition, gas-production in milk.*

In these experiments the 5 per cent. cresol series yielded much less copious growths than the 2 per cent. cresol series, but, nevertheless, even in the former the cloth remained very far from sterile. The following table shows the results :

Experiment.	Test Piece of Clothing.	Treatment.	Cultures.		
			Agar Shake.	*Milk (Anaerobic).*	*Broth (Anaerobic).*
1. (*a*)	Greatcoat	2 per cent. cresol solution	Numerous colonies ; no gas	Acid and clot	Many sporing and non-sporing organisms.
	Tunic	5 per cent. cresol solution	Numerous colonies ; no gas	Acid and clot	Cocci grown ; no anaerobic bacilli present.
1. (*b*)	Greatcoat	2 per cent. cresol solution, followed by fæcal contamination	Abundant gas	"Perfringens reaction"	Numerous sporing and non-sporing anaerobic bacilli.
	Tunic	5 per cent. cresol solution, followed by fæcal contamination	Abundant gas	"Perfringens reaction"	Numerous sporing and non-sporing anaerobic bacilli.
2.	Officer's under-clothing	Washed in 5 per cent. cresol and worn seven days	Numerous colonies	Acid, clot, and gas	Numerous organisms.

These results are so unfavourable that this particular method is an undoubted failure. Further, from both bacteriological and administrative aspects there does not appear to be much prospect of reaching any practicable method of diminishing the grossness of primary infection of wounds by such means. The only possible exception is in the case of flying men. We must therefore be prepared for gross infection of war wounds in almost all cases, and all our efforts must be directed towards the elimination of this infection by appropriate methods of treatment of the wound itself.

II. Initiation of Local Infection

The essential facts relative to the start of the infective process in wounds are—

(1) Introduction of a mass of organisms along with a foreign body.
(2) Local tissue injury, usually of a gross character.
(3) Lack of vigorous general defensive reaction.

These have been considered in part elsewhere, and little need be added here.

(1) The *foreign body* (piece of clothing, etc.) has masses of organisms scattered throughout its substance. Many of these organisms are not in actual contact with the tissues, and are consequently sheltered from direct attack by the defensive agents of the body contained in phagocytes and serum. The foreign body acts, indeed, as a " nidus " in which the organisms are able to maintain their existence almost without molestation. They have thus every opportunity of establishing themselves firmly in the wound before their growth can be checked.

(2) *The gross tissue injury* produced by a modern high-velocity missile has a very profound effect in favouring the onset, not only of inflammation and its sequelæ, but of gas gangrene (see p. 146). A constant feature of the damage produced in the tissue bordering the wound is a direct lethal or sublethal effect on the tissue cells, including damage to the endothelium of the capillary bloodvessels. There follows from this a very rapid outpouring of lymph in the tissue lining the wound, and extending for some distance from it. This " reactionary œdema," as it has been called, appears within an hour or two of the injury. It is a reactive phenomenon designed to aid *defence against infection* by means of the serum and leucocytes which it brings into the wound ; and also to aid *repair* by acting, after coagulation, as a scaffolding for the growth of the tissue which will eventually bridge the gaps. In many wounds, however, this reaction, by its very vigour, becomes inimical. It is accompanied by great swelling of the tissues, causing them (*e.g.*, muscle) to herniate out of the wound in many instances. This may close up the wound of entry altogether and cut off the deeper parts of the wound from access to the oxygen of the air. The lymph fills all the tissue spaces, and accumulates under such pressure as to interfere with the circulation of the part. It also rapidly coagulates, and so forms a mass which is readily changed into inert pabulum for bacteria.

At this stage, therefore, shortly after the production of the wound, we have present in the wound the following ideal conditions for the establishment of infection:

(*a*) A rich variety of fæcal and other bacteria in a " nidus " protecting them from the bodily defences.

(*b*) Dead and devitalised tissue in which these bacteria, including even saprophytes, can readily flourish without much opposition.

(*c*) A mass of coagulated lymph, which partially blocks the blood-supply to the part, and which also may be changed into inert pabulum for the bacteria.

(*d*) Partial or complete anaerobic conditions in the depths of the wound, whereby the growth of the gas-producing organisms is rendered possible.

(3) *Lack of a Vigorous General Defensive Reaction.*—This is the one remaining condition which, if added to the above list, makes the onset of a virulent and rapidly spreading septic process in the wound inevitable. The position could yet be saved in one way only—by a vigorous and healthy resistance on the part of the soldier's bodily defensive mechanism. While such resistance would be unable to prevent the actual initiation of infection under the conditions present, it would tend to check effectively the spread of the process, and, having localised it, would be able in time to render it harmless. This, however, is precisely what cannot be brought about in a great many cases owing to the conditions of fatigue, shock, hæmorrhage, etc., which are so often associated with the wounds of this war, and which handicap the soldier so much in his struggle with wound infection. It is constantly observed, for example, that gas gangrene occurs in any severe degree only in fatigued or shocked men ; and that men wounded in quiet times, who are initially less fatigued and who rapidly receive attention, are much less prone to incur gas gangrene. Diminished resistance owing to fatigue, etc., thus plays a most important part in the initiation of septic processes in wounds.

When organisms begin to grow, they produce, either by metabolism from their own protoplasm or from the protein which happens to be their pabulum at the time, certain complex poisonous bodies called toxins. Their exact chemical nature is unknown, but they have been proved to be products of the disintegration of protein, not uncommonly allied to albumoses. They are of two kinds :

(i) *Endo-toxins*, or insoluble toxins, which remain within the bodies of the bacteria when the latter are grown in an artificial fluid medium.
(ii) *Exo-toxins*, or soluble toxins, which diffuse out into the fluid in which the bacteria are growing.

These toxins produce local and general effects. Locally, they attack tissue cells, and may produce any degree of damage in them up to complete necrosis. The tissue cells, unless killed at once, retaliate by producing antitoxins. The toxins also become absorbed into the blood-stream, and by action on nervous centres give rise to the general symptoms of toxæmia —rise of temperature, rapid pulse, malaise, etc. The amount and the potency of the toxins formed depend upon such factors as—

(*a*) The number and kind of bacteria introduced into the wound.
(*b*) The virulence of these bacteria.
(*c*) The degree of reaction on the part of the patient's tissues, both local and general.

In the case of war wounds, as has been already explained, it is the factor (*c*) which is the most variable, and which, in most cases, determines the extent of the infection.

III. The Reaction to Infection

The Bodily Defences.—Whenever infection is initiated the body reacts, to the best of its ability, by pouring into the wound a fluid consisting of serum and phagocytes. These are the two elements of the bodily defence.

A. The Serum, or lymph, which exudes into infected wounds, is a colloid containing antibacterial substances of various kinds. These substances are rapidly produced by the tissue cells in response to the action upon these cells of toxins derived from the growing bacteria in the wound. Without entering into the theory of toxic action, we may briefly state here that when toxins act upon cells they not only damage the cell, but also stimulate it to produce certain antibodies which have a specific neutralising effect upon the toxins which have caused the damage. These antitoxic and antibacterial substances are rapidly absorbed into the blood, and remain in fine suspension in the serum, whence they appear in the wound in the lymph which becomes exuded as the infective process progresses.

The study *in vitro* of serum which has been so immunised shows that it is capable of reproducing various distinctive reactions, and it is not certain whether these reactions are manifestations of the activity of different kinds of antibodies or are merely different phases of the activity of one kind of antibody. Whichever view be taken, it has been proved that the antibodies in the serum are capable of exerting their action in one or more of the following ways :

(1) As *antitoxins*, or bodies which directly neutralise and render harmless the toxin produced by bacteria.
(2) As *bacteriolysins*, or bodies which attack bacteria directly and cause their lysis or destruction.
(3) As *agglutinins*, or bodies which cause the bacteria to be agglutinated or aggregated into clumps, and so rendered to some extent inert.
(4) As *precipitins*, or bodies which precipitate the specific toxins which stimulated their production.
(5) As *opsonins*, or bodies which "sauce up" the bacteria and render them into a condition whereby they are readily available for phagocytosis.

Whether the antisubstances in the serum, which are demonstrably increased after infection has begun, actually exert these various actions on the bacteria within the wound and the toxins derived from them is not known ; but it is well known that fresh serum has a marked inhibitory effect upon the growth of organisms in artificial culture, and it is certain that, so long as it is fresh, it inhibits the growth of organisms in wounds also. Further, in the case of wounded men suffering from infection, it can be shown, by agglutination and opsonic index estimations, that the inhibitory effect of their serum upon the growth of organisms which have

been isolated from the wound, lymphatics, or blood-stream, is increased. The activity of these antibodies is part of the general vital activity of the body, and it must obviously be diminished whenever that vital activity is low, as in the case of fatigued or diseased men.

When serum coagulates, as it may do when it leaves the circulation and lies in contact with damaged tissue, especially in the presence of infection, or if it encounters an infection which is too strong for its antibacterial powers, it undergoes a tryptic change which causes it to lose its inhibitory power on the growth of micro-organisms, and, indeed, renders it into an inert mass of pabulum for these bacteria. So long, however, as the lymph-circulation between the blood-stream and the tissue of the wound remains active, the serum has bactericidal powers and should be utilised in all schemes of treatment; and, in passing, it may be observed that this is a fundamental of the Carrel method of treatment of wounds, and that "drainage" in the old sense of removing healthy serum and phagocytes from contact with the infected surface is a practice to be deprecated.

B. The Phagocytes constitute the second element in the bodily defensive mechanism. They consist of (1) polymorphonuclear leucocytes of the blood; (2) large mononuclear leucocytes; and (3) large endothelial cells from the lining of lymph glands, tracts, and spaces. These various cells are attracted by a process of chemiotaxis to the spot where bacteria are endeavouring to establish their growth. The process of phagocytosis, whereby these cells attack, envelop, ingest, and destroy the bacteria, or are themselves destroyed, is a very familiar one. It can be easily demonstrated under the microscope in connection with any sufficiently infected wound exudate. There is, however, more in it than meets the eye. There is the subtle influence which guides the phagocyte towards its prey; there is the means by which the organism is, so to speak, "paralysed" and rendered into suitable prey (opsonins); and there is the means (the perfect organic antiseptic) by which the organism is killed before or after the phagocyte enfolds it. The final lysis of the bacterial substance within the cytoplasm of the phagocyte is probably accomplished by the action of ferments.

In the primary stages of wound infection, the polynuclear leucocytes are the predominating phagocytes, possibly because they are more mobile; in the later stages the very actively phagocytic mononuclears and endothelial cells (the macrophages, as they are called) become relatively increased, and in the last stages may outnumber the other. In the case of infection in serous membranes, however, such as the peritoneum, the pleuræ, and the synovial membrane of joints, the macrophages, which are normal inhabitants of these structures, are relatively numerous from the beginning, and large numbers of them in a healthy condition are of good prognosis.

These two elements of the bodily defensive mechanism, the serum and the phagocytes, are interdependent in their action. They are each prac-

tically functionless in the absence of the other, and the assault which they make is always a combined one.

There are other cellular elements which appear in wounds—namely, lymphocytes and tissue cells (the small mononuclears), and it is probable that they, too, play a minor part in phagocytosis or, at least, in immunity. They seem to be capable of forming antitoxins and other antibacterial substances, but their further action, if any, is quite unknown. They are present in relatively large numbers in the wound exudate in the earlier stages of infection, when the lymphocytes probably play some unknown subsidiary part in phagocytosis, and the tissue cells are doing their best to repair the damaged structures, and are at first separated off in the process. In the later stages no lymphocytes are seen, and the tissue cells, too, are scanty, since they remain attached to the growing granulation tissue.

IV. The Progress of Infection

The local infection in a wound may progress in one or more of three directions:

(1) Localised suppuration.
(2) Spreading inflammation and suppuration in special structures—*e.g.*, bone, tendon, and cellular tissue.
(3) Gas gangrene, localised or spreading.

The macroscopic appearances associated with localised and spreading inflammation and suppuration are too well known to require description here, and the naked-eye pathology of gas gangrene in wounds is considered in another chapter. The *microscopic history of wounds* is, however, a recently developed branch of surgical pathology, and, on account of the valuable information which it yields to the surgeon, it will be dealt with here in some detail. It is convenient to take as a model a large flesh wound showing localised gas gangrene, for that is perhaps the most typical of all war wounds, and its microscopic history while undergoing sterilisation by the Carrel-Dakin method will be sketched. This can be studied only at the casualty clearing station and the base hospital.

Methods of Investigation.—The chief method is the examination of daily or two-day successive direct films from various prominent and distinctive features in the wound, including always the part where the tissues are least healthy or the wound exudate thickest. The phagocytic power of the cells may be tested by Colonel Bond's iodophil reaction or by the staining reactions of the cells. Valuable information is also obtained by making cultures, but this method is much more laborious.

It is necessary to state that a wound during the progress of the infection consists of various quite distinctive features, such as *dry hyperæmic tissue, suppurating tissue, gangrenous tissue, sloughs of granulation tissue and of muscle, ligament, and tendon, necrosed bone, sequestrated bone, cavities containing*

gravitated wound exudate, sinuses, undermined areas, healthy granulations, etc. Some of these are characteristic of the earlier and some of the later stages of infection, but many of them may be present in a wound at the same time. It is necessary, therefore, in representing the state of infection of a wound by figures and symbols descriptive of the number of organisms and the type of cells present, to specify the part of the wound from which the exudate has been taken. In this way, by means of a series of films made at daily or two-day intervals during the sterilisation of the wound, the progress and the pathological history, not only of the wound as a whole, but of each part in particular, can be watched.

In practice, " bacterial charts " have been constructed by Carrel and others to represent graphically the progress of the wound infection. Daily films are made from the dirtiest part of the wound, the number of organisms in twenty microscopic fields is counted, and the average taken.

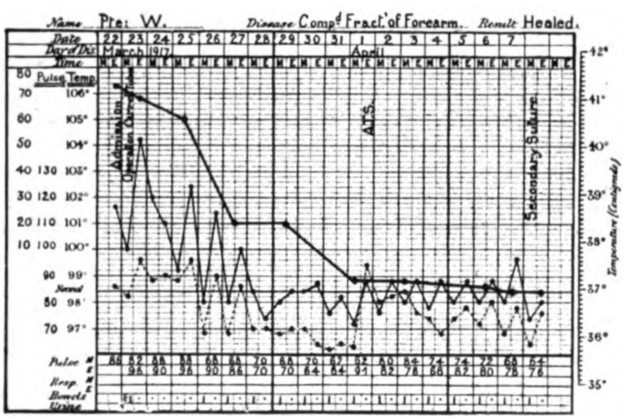

FIG. 23A.

Thin line shows temperature ; dotted line shows pulse ; thick line shows organisms per field.

The " number of organisms per field " thus obtained is the figure for the day. The variations in this figure from day to day and the gradual or ultimate downward tendency can easily be represented by a coloured line on the temperature chart or on a separate chart.

In a series of about 150 wounds which the authors investigated in this way, special forms were used representing the state of the wound infection more completely than by a single figure. The information noted on these forms after examination of the smears embraced not only the average number of organisms per field in various situations in the wound, but their apparent nature, the relative proportion of bacilli and cocci, the percentage of organisms intracellular, the relative proportion of healthy and degenerate cells, the relative proportions of polynuclears, small round cells, and macrophages present, and, in

a number of cases, the organisms isolated on culture. These forms, when completed up to the time of secondary suture, gave a fairly complete representation of the microscopical history of the wound, and it is on the information so gained that we base most of the findings described in this chapter.

TECHNIQUE OF DIRECT FILM EXAMINATION.—The apparatus required is shown in the illustration (Fig. 24)—viz., a platinum wire, a spirit-lamp,

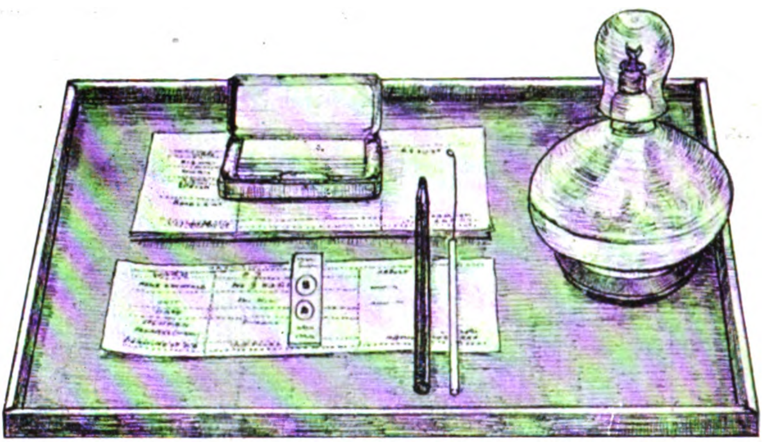

FIG. 24.

a box of clean slides, a pencil for writing on glass, and some forms on which to write the report. These materials are taken to the bedside of the patient when the daily or two-day dressing is being done, and the smears are made by means of the platinum wire as shown in the illustration (Fig. 25). The platinum wire is sterilised in the flame of the spirit-lamp, and a loopful of

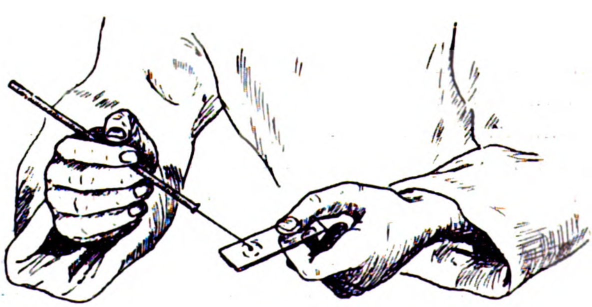

FIG. 25.

wound exudate is removed from the various parts of the wound which it is desired to test. In most cases one or two smears suffice, and these should always include the dirtiest part of the wound. A loopful of wound

exudate is taken directly after removal of the dressing, and before any of the discharge has been removed by irrigation with the hypochlorite solution. As far as possible, the exudate is taken unmixed with the antiseptic fluid, and in the case of granulation tissue it is particularly important to avoid taking up a loopful of blood. The smears are made by spreading out the loopful of exudate in circular fashion to form a smear which varies in size from a shilling to a florin, according to the amount and thickness of the material. If two or three smears are made from one wound or one person's wounds, they can be made on the same slide. The smears are ringed, on the back of the slide, by means of the grease pencil as shown in the illustration, and appropriate abbreviations are written under each ring to indicate the position or nature of the part of the wound from which the smear was made. For example, smears may be labelled "rt. thigh ant." for "anterior wound of right thigh," "sin. post." for "sinus posteriorly," "surf. lat." for "lateral surface," etc. If preferred, each smear can be denoted by letters, *a*, *b*, *c*, etc., and corresponding letters, with a description of the part to which they refer, written on the report form. We have, however, found it more convenient to write even copious notes on the back of the slide by means of the grease pencil.

A number is now written on the back of the slide, and a corresponding number written on a report form, together with the other particulars desired, such as *name*, *ward*, *date*, *character and position of wounds*, *date of infliction of wound*, etc. The slides are then dried over the flame, fixed by passing through the flame, and finally rolled up in the appropriate report form and taken to the laboratory.

The smears are stained with Kühne's carbol-methylene blue* for three minutes, and where duplicate smears have been made these are stained by Gram's method, in order to identify certain groups of organisms present. Carbol-methylene blue is the stain which we have come to rely upon as the best for routine work. The following are among its advantages: (1) It gives a beautifully clear picture, the nuclei of the cells being well differentiated from the cytoplasm, the former being stained deep blue and the latter light blue; (2) organisms take the stain very readily, and they can be easily picked out; (3) when blood-corpuscles are present in the film they are stained green, thus differentiating them at once from lymphocytes and tissue cells, which may sometimes be confused with them when a single simple stain is used; (4) it clearly shows up any trace of degeneration of the phagocytes, as the nucleus, instead of staining deep blue in such a condition, tends to a purple shade; moreover, fragmentation of the nucleus is easily seen, and the cytoplasm is very lightly stained.

* Kühne's methylene blue:

Methylene blue	1·5 grms.
Absolute alcohol	10 c.c.
Carbolic acid solution (1 in 20)	100 c.c.

The "Iodophil Reaction" Method.—This test has been introduced by Colonel Bond in order to determine the degree of phagocytic power possessed by any leucocytes. The essential element of the test can be studied as follows:

Obtain a film of perfectly healthy leucocytes from normal blood, either from the leucocytic layer between the serum and the red blood-corpuscles after the blood has been centrifuged, or by incubating blood in a plasticine cell for one hour at 37 ° C. until the leucocytes emigrate from the clot and form a layer adhering to cover-glass and slide. Mount these healthy leucocytes in normal saline, and allow 1 per cent. watery iodine to run in under the cover-glass. At once there is seen, in a considerable proportion of the leucocytes in a field, a mauve-coloured exudation, which collects within the cell and is quickly extruded until it forms a little mauve spherical colloidal mass of iodophil substance adhering to the outside of the cell which has expelled it. Ultimately these colloidal masses break away from the cells and float free in the fluid. The reaction is seen best in a certain zone of the cover-slip preparation where the iodine reaches a certain concentration. The amount of this mauve-coloured substance varies with the phagocytic power of the cells, and in any film of leucocytes in which it is not seen, or seen in very slight degree, the leucocytes are incapable of active phagocytosis. In the case of wound exudate the reaction is said to be present in cells which have free egress from the wound, such as those on the surface. Where the cells are shut in and have no free flow, as in a sinus, the reaction is absent.

The authors have applied this method to wounds undergoing sterilisation by the Carrel-Dakin treatment and have found that, except in the earliest stages—*i.e.*, during the first three or four days in the case of a gangrenous wound—the cells of the wound exudate generally give the reaction in large measure. The reaction is readily obtained in the case of the cells of sump wounds, and even of sinuses, provided that hypochlorite solution is regularly instilled into the sinus. We have not found that the reaction yields any more information than can be obtained by inspection of films of wound exudate well stained by carbol-methylene blue. By using this stain, it is easy to pick out at once the healthy cells by the intense blue staining of the nuclei and the distinct light blue cytoplasm. The cells which are less healthy stain less intensely, and show some fragmentation of the nucleus, while those which have performed phagocytosis and are rather the worse for the struggle have nuclei which are deficient in chromatin and *tend to stain purple*. This purple staining of the nuclei is often seen also in those pale-staining cells which are obviously degenerate, and in those which are frankly breaking up. An additional advantage in gauging the functional activity of the cells of wound exudate by means of staining reactions in dry films is that phagocytosis can actually be observed, the proportion of organisms intracellular can be roughly estimated, and the condition, in particular, of the cells which have ingested organisms can

be noted. These points, which can be taken in almost at a glance, provide important additional evidence on the question of the degree of phagocytic power possessed by the cells as a whole.

DESCRIPTION OF MICROSCOPIC DRAWINGS.

Figs. 26-30 represent the microscopic history of a heavily-infected gas-gangrenous flesh wound treated by the Carrel-Dakin method. The smears were made from the dirtiest part of the wound at intervals of two days. The drawings represent a small part only of a typical field. Magnification × 800. Stain, Kühne's carbol methylene blue.

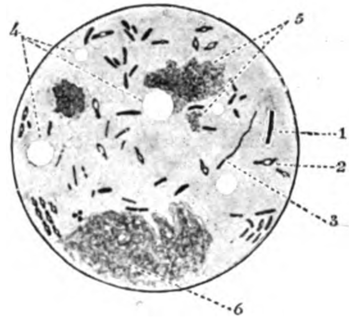

FIG. 26.—Gangrenous stage.

1, Non-sporing form of anaerobe ; 2, sporing anaerobic bacilli ; 3, filamentous form of anaerobe ; 4, fat globules ; 5, tissue débris ; 6, necrosed tissue.

Gangrenous wound third day. Wound excised two days previously. Recurrence of gangrene in fresh wound surfaces. Smear made from black gangrenous tissue. Note the large number of sporing, non-sporing, and filamentous anaerobic bacilli ; absence of cocci and the smaller aerobic bacilli ; cells are practically absent ; no polynuclears at all ; numerous fragments of necrotic tissue and tissue débris ; and minute globules of oil from the disintegrated tissue.

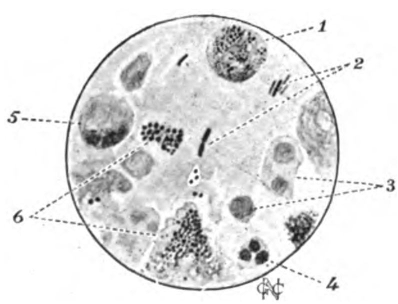

FIG. 27.—Sloughing stage.

1, Necrosed polynuclear invaded by cocci ; 2, anaerobic bacilli ; 3, tissue cells ; 4, healthy polynuclear ; 5, degenerate polynuclear ; 6, masses of cocci.

Localisation of the gangrenous process has occurred, and the affected tissue is sloughing. Smear made from a separating slough. Cells are now present, but stain faintly and show little detail of structure. Polynuclears degenerate, and many are crammed with organisms. Degenerate tissue cells and elements, and tissue débris still present in quantity. The large anaerobic bacilli are now relatively few, and great masses of cocci, and small bacilli, have taken their place.

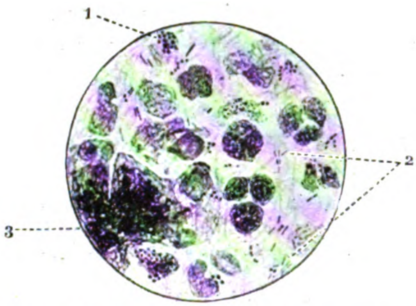

FIG. 28.—Early granulating stage.

1, cocci ;
2, small bacilli (aerobic) ;
3, microscopic slough.

Smear made from thick exudate on granulating surface. Polynuclears numerous, and still stain rather faintly. Active phagocytosis in progress. A microscopic slough is represented, consisting of a degenerate mass of tissue cells mixed up with organisms, and more or less surrounded by a zone of polynuclears. Organisms are very numerous, and consist entirely of cocci and small aerobic bacilli ; anaerobes have completely disappeared.

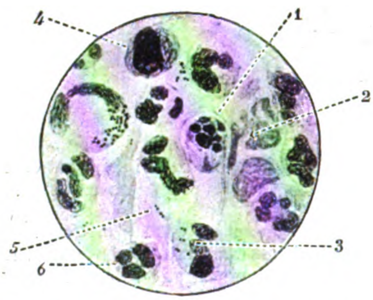

FIG. 29.—Late granulating stage.

1, tissue cell with fragmenting nucleus ;
2, "exhausted" cells (purple nuclei) ;
3, intracellular diplococci ;
4, macrophage ;
5, diplococci ;
6, healthy polynuclear.

Smear made from wound exudate, which is now much less copious. Cells stain well and have a healthy appearance ; they are mainly polynuclears, but occasional tissue cells and macrophages are seen. Some of the older or more "exhausted" cells show a purplish staining, large-meshed nuclear chromatin. Organisms much less numerous, and most of them are intracellular. Streptococci (in diplococcal form) predominate.

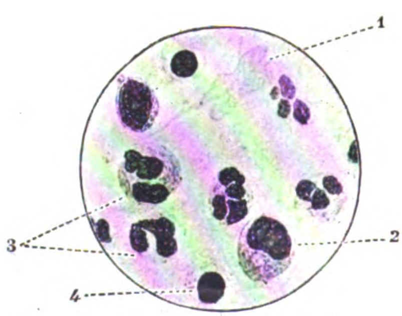

FIG. 30.—Stage of surgical sterility (for secondary suture).

1, "exhausted" polynuclear ;
2, healthy macrophage ;
3, healthy polynuclear ;
4, tissue cell.

Smear made from thin mucoid wound exudate. Cells are almost all healthy and are relatively less numerous. Polynuclears predominate, but the proportion of macrophages is greatly increased. Tissue cells are common. An old polynuclear with purple staining nucleus is shown. No organisms are shown in this part of the fluid, but a few cocci are present in the smear, averaging not more than 0·4 per field.

This wound was sutured and healed by first intention on eleventh day.

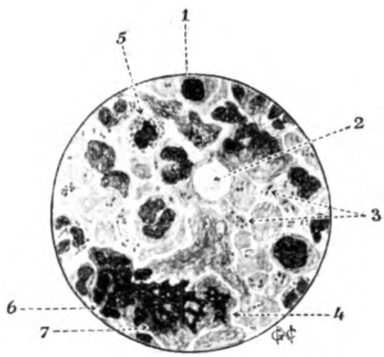

FIG. 31.—Early granulating stage in a compound fracture.

1, Tissue cell; 2, oil globule; 3, cocci and small bacilli; 4, microscopic bone slough; 5, polynuclear with ingested oil globules, and granules; 6, zone of polynuclears; 7, degenerate tissue cells.

Corresponds to Fig. 28. Cells stain deeply (a typical feature in bone cases). Polynuclears predominate, and active phagocytosis is in progress. Tissue cells are very common. A microscopic bone slough is represented, consisting of a fragment of bone showing canaliculi, and accompanied by a degenerate mass of tissue cells and a zone of polynuclears. Fat globules and pigment from bone-marrow are represented. Organisms are numerous, and consist of cocci and small bacilli; no anaerobes seen.

The succeeding stages in a compound fracture are similar to those shown above.

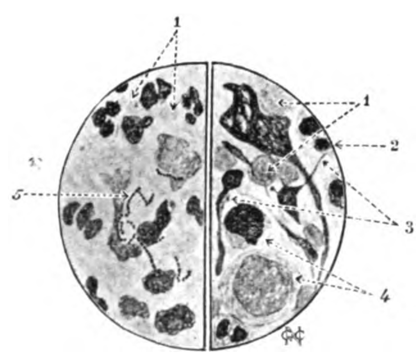

FIG. 32. Two common errors in technique of treatment.

1, Red blood-corpuscles; 2, polynuclear; 3, fibroblasts and fibres; 4, macrophages; 5, long-chained streptococcus.

Left half represents a smear from a wound in the "late granulating stage." The organisms are almost all in the form of long-chained streptococci. This never occurs where sterilisation is proceeding satisfactorily. The smear suggests (*a*) presence of a foreign body or necrosed bone or retained pus, or (*b*) insufficient access of fluid to all parts of the wound. Possible lines of treatment are: (1) correction of the surgical defects, where this can be safely done; (2) autogenous streptococcal vaccine.

Right half represents a smear from a wound which has passed the "stage of surgical sterility," and become dried up and covered with a thick layer of granulation tissue. Polynuclears are few; macrophages, tissue cells, and fibres, and other tissue elements, predominate, and there is a fair sprinkling of red blood-corpuscles (stained green).

Sterilisation has here proceeded too far, and the object of secondary suture is largely defeated owing to the thickness of the cicatricial tissue produced.

The Microscopic History of Wounds.—We may now trace the various stages through which an infected wound passes during sterilisation, according to evidence derived from successive daily microscopic examinations of the wound exudate. A very typical war wound is selected as a model—viz., a large localised gangrenous flesh wound, say, of the buttock, or a compound fracture of the femur. When such a wound is treated by the Carrel-Dakin method, the following stages may be noted :

(1) *Hyperæmic and Œdematous Stage.*—Smears of the wound taken at the casualty clearing station during the first day show degenerate tissue cells, lymphocytes, endothelial cells, scanty polynuclear leucocytes, and few organisms. The organisms are chiefly large Gram-positive bacilli (*B. perfringens* group), and there may be a few diplococci (*Streptococcus fæcalis*). The infection has but begun, and neither have the organisms multiplied greatly nor have the tissues yet put forth their defensive power. In a wound which is becoming gangrenous, however, the large anaerobic bacilli develop with amazing rapidity.

(2) *Gangrenous Stage.*—This may be seen at the casualty clearing station. A gangrenous, foul-smelling pellicle lines the wound track, and there may or may not be gas extending into the tissues. Smears from the gangrenous area at this stage show a mass of organisms, almost all bacilli and relatively few cocci. The predominant organisms are *B. perfringens*, coliform bacilli, and Vincent's bacillus. The cells are very scanty and very degenerate, and consist of scattered tissue cells, lymphocytes, and endothelial cells. Polynuclears are absent, for they cannot penetrate into gangrenous tissue.

At this stage, or before it, the wound is usually excised, and, as complete excision is impossible in the majority of cases, there remain to be sterilised the freshly infected cut surfaces. This process is commenced by inserting a sufficient number of Carrel's tubes into the excised wound, and the case is sent to the base hospital, usually on an ambulance train. During the journey on the train the hypochlorite solution is instilled hourly or two-hourly through the Carrel's tubes.

When the base hospital is reached, the condition of the wound depends entirely upon the thoroughness of the preliminary surgical excision, the technique of the insertion of the Carrel's tubes, and the diligence and regularity with which the hypochlorite instillation has been carried out. If all these conditions are favourable, the wound will usually arrive at the base hospital comparatively clean, the infection having been checked and further gangrene and suppuration prevented. The wound can then be secondarily sutured within a day or two of the arrival at the base hospital. If, however, the conditions are unfavourable—*e.g.*, by reason of incomplete excision, inefficient application of tubes, unfavourable general condition (fatigue, shock, hæmorrhage, etc.), unfavourable local condition (severe comminution of bone, etc.), insufficient hypochlorite instillation, etc.—the reinfection in the excised wound spreads and gangrene reappears. Thus

the wound may arrive at the base hospital still in the gangrenous stage, and smears will then show the features which have been already mentioned. There is nothing for it but to see that the Carrel tubes are properly inserted, and to introduce the hypochlorite solution regularly and without fail every hour. The gangrenous tissue will then rapidly disappear, more quickly in some parts than in others; exudation becomes poured into the wound, and the process of separation of the sloughs begins. As this goes on, the film picture changes. The cells, which were scanty and degenerate, rapidly increase in numbers, and polynuclears reappear. The character of the bacterial flora also undergoes a change.

(3) *Sloughing Stage.*—Around the masses of gangrenous tissue, yellow purulent exudate appears within a day or two, and this exudate increases until the whole wound may be almost bathed in it. Gradually, as a result of the ferment and phagocytic action of the leucocytes, and of the solvent action of the antiseptic (Dakin's solution or eusol), the gangrenous tissue separates, mainly as microscopic but sometimes as macroscopic sloughs. Smears from the purulent exudate in this stage show an abundance of polynuclear cells, moderately healthy, numerous tissue cells, mostly in the form of little separated masses of degenerate cells (microscopic sloughs), a few lymphocytes, and very scanty macrophages. The organisms are very numerous, usually upwards of 100 per field. The relative proportion of bacilli and cocci has changed, and we now find that the bulk of the organisms are Gram-positive cocci (streptococcus and staphylococcus) and small bacilli (coliform and diphtheroid organisms, etc.); while the large, stout, Gram-positive bacilli (*B. perfringens*) and all large sporing bacilli are greatly diminished in numbers. The saprophytic element in the wound infection is being gradually eliminated, and the more resistant parasitic flora are in the ascendant.

(4) *Granulating Stage.*—Within two or three days more there begin to appear at various points in the wound surfaces little red islets of granulation tissue, raising their heads from out of the pool of purulent exudate. These appear first in the parts of the wound occupied by superficial fascia and by muscle. Dense deep fascia (*e.g.*, fascia lata), ligament, tendon, and bone, are much more resistant to sterilisation, and the sloughs of these structures take much longer to separate. Gradually the islets of granulation tissue unite and form a layer, which, in spite of repeated partial destruction and sloughing, repairs itself, and spreads until it covers the whole wound. This process takes a very few days, unless there be some specially resistant slough present—*e.g.*, dense fascia or ligament or bone—when it is delayed for a week or two until the slough separates. The rest of the wound becomes meanwhile covered with granulation tissue.

Smears from the granulation tissue exudate show abundant *healthy*, intensely stained polymorphs as well as tissue cells, which are discrete and in little masses surrounded by a zone of leucocytes. The central cells of the masses are degenerate (microscopic sloughs), but the discrete tissue

cells, as well as those at the periphery of the masses, are usually moderately healthy ; macrophages may be present in rather greater numbers, but are still relatively few. They stain well, and can often be seen actively ingesting organisms, and even the more degenerate polynuclears. The organisms are much diminished in numbers, and the cocci are now much more numerous than the bacilli. So long as sloughs remain in the wound, occasional large Gram-positive bacilli (usually *B. perfringens*) can be seen ; but in most wounds these disappear altogether when sloughs are dissolved away, and commonly rather earlier than this. Coliform bacilli usually disappear about the same time. When sloughs have been removed, the organisms which are commonly cultivated from the wound are streptococcus, staphylococcus, and diphtheroid bacilli. *B. pyocyaneus* appears very rarely in a wound treated by the Carrel-Dakin method, and on those rare occasions in which it does appear strong suspicion should be entertained of an error in technique. It disappears quickly when a wound is efficiently and vigorously watered with hypochlorite solution.

During the *granulating stage* the bacterial count falls rapidly to an average of three or four per field. If the rule be followed of taking smears only from the dirtiest part of the wound, the bacterial count remains high until all sloughs have disappeared, and then a sudden fall occurs to three or four per field, or even less.

In the case of compound fractures, certain slight differences are observed during the sloughing and granulating stages.

Microscopic sloughs are much more common and characteristic. They have an intensely staining, undifferentiated granular mass in the centre, which seems to consist of a minute piece of necrosed bone with bone cells. Around this central mass is grouped a zone of large deeply staining tissue cells, with cytoplasm somewhat square in form and a relatively small, round, dark nucleus. There are numerous polynuclear cells infiltrating this zone, and these cells also form another distinct zone around the tissue cells.

In the latter part of the granulating stage, the necrosed centres of these masses no longer appear in the exudate, but grouped tissue cells of large size can still be seen, as well as the ordinary discrete connective-tissue corpuscles. In these groups of tissue cells there are commonly seen certain large cells with a relatively large deeply staining nucleus. These cells have all the appearance of healthy osteoblasts, and, if such be the case, would appear to indicate that bone repair is proceeding at these stages actively.

(5) *Dry Stage.*—A change in the granulating stage takes place soon after all sloughs have been removed. Healthy granulations now line the entire wound surface, except in the case of certain severe compound fractures, in which the process is considerably delayed. Discharge diminishes, and the wound enters once more upon a dry stage. Smears show that polymorphs are absolutely and relatively diminished, and are

almost all active and healthy. Purple staining of nuclei is practically absent, connective-tissue cells are much fewer and are isolated cells in the discharge, and no masses of them can now be seen. The most characteristic feature of the cytology is the largely increased number of the macrophages. They are very large cells at this stage, each with a large round-meshed nucleus and often one or two nucleoli. They are actively phagocytic, and can often be seen ingesting organisms and also the older polymorphs. The organisms diminish rapidly during this stage. They usually consist entirely of cocci in diplococcal form, but sometimes include small diphtheroid bacilli.

(6) *Stage of "Clinical Sterility."*—This stage follows rapidly upon the "dry stage," except in a few unfavourable cases. The cells as a whole diminish in numbers still more, and polymorphs may become very greatly decreased, endothelial and isolated granulation-tissue cells being seen in abundance. The organisms diminish within a few days to the figure which stands for "clinical sterility," which is the maximum which usually allows of secondary suture being performed without fear of the wound breaking down. This standard is usually fixed in France at one per field, but the authors prefer a rather lower standard—viz., 0·4 per field, or an average of two organisms per five fields. This was found to give the best results in a series of over 600 secondary sutures of all kinds. In a large number of cases the sterility obtained was almost absolute, no organisms being seen in twenty to forty fields of a film preparation.

The essential film characteristics in the stage of "clinical sterility," then, are as follows:

(*a*) A maximum bacterial count of 0·4 organism per field, the average being taken over twenty fields.
(*b*) Polynuclears comparatively few.
(*c*) Macrophages numerous.

Time Required for Sterilisation of Wounds.—The above description of the successive film pictures during the sterilisation of a wound by the Carrel-Dakin method refers to a severely infected flesh or ordinary compound fracture wound showing localised gangrene after excision. Such are very typical wounds.

In the case of less severely infected wounds, with good excision, the whole course of sterilisation may be very short, and suppuration very slight. But even in such wounds there are many cases in which, though the earlier stages are short or absent, the suppurative stage may be fairly persistent. When this occurs, the granulation tissue lining the wound can often be seen to be full of little crypts in which the bacteria of the wound flourish, and which are very difficult to sterilise. In such wounds the bacteria invade the granulation-tissue wall to some depth from the surface. This indolent condition of the granulation tissue undoubtedly occurs in many cases as a result of insufficient flushing of the wound with hypo-

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chlorite solution in the early stages. A certain proportion, however, of such indolent infections of wounds on the Salonika front seemed to be due to malaria.

The time required for sterilisation in the first series of 200 secondary sutures performed at this hospital was ten to fifteen days for flesh wounds, and seventeen to twenty-eight days for compound fractures. Our later series of 400 cases yielded much better results, possibly owing to a more complete excision at the casualty clearing station, as well as to increased experience on the part of the medical and nursing staff. Flesh wounds in this series were sutured in from four to twelve days, and compound fractures in from six to twenty-eight days.

Delayed Sterilisation of Wounds.—In any large series of wounds, however, there are a number of departures from the ordinary routine. Special difficulties are created by the presence of severe comminution of bone, large gaps in bone, sequestrating bone, unremoved foreign bodies, wounds, generally, which do not lend themselves to complete or almost complete excision, spread of infection to neighbouring structures such as joints, or the onset of spreading cellulitis, osteomyelitis, and septicæmia. In such cases it is essential that the technique of the Carrel treatment be very strictly carried out, and that each part of the wound receives a liberal supply of the antiseptic.

We have very often found, over a large series of cases, that undue delay in sterilisation is accounted for by want of attention to the details of the technique of the dressing and of the irrigation. In no system of surgical treatment does so much depend upon the medical officer or sister who does the daily dressings. The dressings and irrigations do not merely set free discharge and relieve pain and pressure, as in the older methods, but they play an active part in diminishing the sepsis. The offensive measures against the organisms of the wound are not entirely confined to the serum and phagocytes of the body as heretofore, but a definite part in the offensive is taken by the antiseptic. The success of this part of the offensive depends, therefore, entirely upon the technique employed, and it is of the utmost importance to give each detail of technique the most strict attention.

In those cases in which the efficient practice of the details of technique is above suspicion, and delay in sterilisation yet occurs, it may be necessary to consider the question of further surgical measures.

In the bone cases, if there be sufficient access to all infected parts, sterilisation should be persisted in, and, if possible, more Carrel tubes inserted into the wound, and irrigation carried out at more frequent intervals—*e.g.*, hourly. The most gross suppurations in bone can often be sterilised in four to six weeks in this way, as, for example, in the case of astragalectomies with severe suppuration of the tarsal bones. Where access to the bone or base of the wound is not readily obtained and there is undue delay in sterilisation, as shown by successive smears, it is well to subject the

wound to a further and more complete surgical exposure and preparation. The risk of septicæmia is not unduly great if care be taken in handling the tissues, and hypochlorite irrigation recommenced vigorously immediately after the operation.

Effect of Other Methods of Treatment on the Sterilisation of Wounds.—The older methods of wound treatment, such as daily dressings, with irritating antiseptics of the biniodide of mercury, carbolic acid, and methylated spirit types, daily dressings with eusol, and hypertonic saline treatment, have deservedly fallen into disuse in routine work. If either of the two latter methods is employed as subsidiary to the Carrel-Dakin treatment in the course of the sterilisation of a wound, a contingency which occasionally arises, the wound is very apt to become reinfected, the organisms present rapidly multiplying and invading the wound in large numbers. Time is lost and some days of active Carrel treatment are required to bring the wound again to its former condition as regards degree of infection.

The group of antiseptics introduced by Browning and his co-workers for the treatment of gunshot wounds—viz., the flavine compounds and brilliant green—are in a different category. Their action and uses are discussed in the chapter on "Antiseptics" (p. 223), and the information obtained by the study of successive smears of the wound exudate, when these antiseptics are used, is also set down. It is shown that when flavine is employed on severely infected wounds the number of cells and of organisms in the exudate diminishes markedly for the first three to five days, but that after that time the number of organisms increases, and does not show the tendency to gradual and rapid fall which is seen in the case of wounds treated by the Carrel-Dakin method. The organisms which reappear in the discharge are not mainly cocci, as in the later stages of the latter method, but include a goodly proportion of spore-bearing anaerobes and of coliform bacilli. Thus, the effect of flavine on the organisms in the wound, as judged by smears, is quite different from that of the hypochlorite solutions, and hence by the use of a combination of antiseptics in the sterilisation of a wound, it is possible sometimes to break up the symbiosis (*vide* p. 46) of the organisms, and so produce a more rapid sterilisation. It has already been shown elsewhere that the symbiosis of organisms is a most important factor in maintaining their virulence and power of growth. In a number of cases this method has been used with success, flavine or brilliant green being employed in the form of gauze dressings for the first few days, and, after that, the Carrel-Dakin method being substituted. This however, complicates the procedure, and we prefer the Carrel-Dakin method from the commencement except in non-gangrenous wounds in which complete or almost complete excision appears to be possible. It has been frequently observed that, if a wound has been almost completely excised at the primary operation, and either flavine or brilliant green then applied, clinical sterilisation becomes complete within

two or three days in a considerable proportion of cases. In such successful cases it is, of course, unnecessary to substitute the Carrel-Dakin method at a later date, but in the less favourable cases it is well to substitute that treatment after three to five days. This method has been successful in our hands with the smaller flesh wounds and a few cases of compound fracture. It has not given good results in wounds already gangrenous, or in those which have become so through incomplete excision. In these the solvent action of the hypochlorite solutions has been invaluable in removing sloughs and producing comparatively rapid sterilisation, as has been already fully described.

V. The End-Results of Local Infection

Primary and Secondary Suture of Wounds.—In the modern treatment of all war wounds, except the very smallest, there are only two methods of final closure of the wound which deserve consideration at all. These are primary suture and secondary suture. The older method of allowing the wounds to heal by second intention is far too slow, uneconomical, and unsatisfactory for application to the wounds of this war. Surgical excision of war wounds is now universally recognised to be the correct preliminary procedure in the great majority of cases, in order to reduce the dangers consequent on infection. Excision leaves large gaping wounds, which, if left to heal naturally by granulation from the bottom, would keep men in hospital for many months, would entail enormous expenditure on dressings, and would result in broad painful scars, easily chafed and ulcerated by a soldier's equipment, and rendering the wounded man in most cases unfit for further active service.

Primary Suture.—When excision of a wound has been performed (at the casualty clearing station as a rule), the question arises as to whether the surgeon should suture the wound primarily or whether he should leave the excised wound surfaces open to be treated by some antibacterial method until infection has been sufficiently subdued to permit of secondary suture being performed. Primary suture is undoubtedly the best from every point of view, if it can be safely performed. The criteria for primary suture of wounds are, so far, mainly clinical. The bacteriological aspect of wound infection at this stage has not yet been sufficiently worked out to permit of a bacteriological criterion being formulated. In this respect primary suture differs markedly from secondary suture, and hence the results of the former are much less uniform and uncertain. The essentials of primary suture are as follows :

1. Excision of the wound should have been performed preferably within twelve hours, and in no case later than twenty-four hours, after the infliction of the wound.

When infection spreads in a wound track, the bacteria at first lie on the wound surfaces. As infection progresses, however, they find their

way into the deeper tissue layers, where they are much more difficult of removal. After twenty-four hours the chances of removing the complete infection by ablation of the wound track are much diminished.

2. The wound should be, as far as possible, *completely excised.* This is a purely surgical matter. It is difficult, if not impossible, in some wounds. It can, however, be accomplished in some apparently hopeless cases by the method of *piecemeal excision.* The method of preliminary staining of the wound track with brilliant green, as used by Hey, appears to give valuable information as to the extent of the track, and therefore of the surgical procedures required.*

3. An antiseptic should be used in the wound which is non-injurious to the tissues, acts well in the presence of serum, and has a prolonged action. Such an antiseptic we now have in flavine, and, to a slightly lesser extent, in brilliant green.

4. The presence of gas gangrene is a contra-indication.

5. A surgeon thoroughly experienced in war surgery is essential. A small series of wounds in which these conditions were satisfied, and including even compound fractures, did extraordinarily well with primary suture, and avoided all the dangers and complications associated with open septic wounds. Such wounds resulted in little more disturbance than a clean surgical operation.

There is always infection in such wounds, for no matter how complete the excision, it is next to impossible to secure that the new wound surfaces remain absolutely uncontaminated. The infection which remains, however, is mostly superficial, and is easily disposed of while in that condition by the application of flavine or brilliant green to the wound before suture. The flavine should be applied freely to the wound surfaces. The suture is then performed over the antiseptic, and in most cases a Carrel's tube is left in the wound and fixed at one corner by the sutured edges. Through such a tube flavine can be liberally applied to the wound surfaces on the operation-table, and subsequently at six-hourly or eight-hourly intervals, for two days. The other method of application of antiseptics in the form of pastes in cases of primary suture is referred to elsewhere (p. 235).

If in any case of primary suture sepsis of any considerable degree appears in the wound within a few days, the wound should be reopened and the Carrel-Dakin treatment applied.

Secondary Suture.—At the present stage of war surgery this is the more common and more convenient of the two methods of closure of wounds. It is an essential part of the Carrel-Dakin treatment, which has been designed to obviate the risks which, except in the most capable and experienced of hands, are associated with primary suture, and, at the same time, to produce an end-result which is almost as good as that obtained by primary suture. After the wound has been excised as far as possible, vigorous and continuous sterilisation of the reinfected surfaces is carried

* *British Medical Journal*, October 6, 1917.

out by means of Dakin's solution or eusol applied through Carrel's tubes. The wound, having passed through the stages of infection which have been above described, is ready for secondary suture when it reaches the stage of "clinical sterility." The bacteriological standard of "clinical sterility" is usually estimated at an average of one organism per field; but the authors have, as already stated, obtained better results by using the lower standard maximum of 0·4 per field, or two organisms per five fields. The personal factor enters into the estimation to some extent, and may account for some of the difference. In most cases, however, we have found "one per field" too high for perfect primary union.

Bacteriology and Secondary Suture.—In a series of some 600 secondary sutures performed at a base hospital it was clearly proved that clinical tests alone for secondary suture were unreliable, and that the only sure way of avoiding failures was to rely upon the bacteriological control. For example, not a few cases occurred in which the wounds looked clean enough, clinically, for suture, and yet films showed the bacterial count to be from twenty to fifty organisms per field. Any attempts that were made to suture such wounds ended in disaster. The wounds never healed by first intention; some gaped in great part and healed slowly; most of them broke down completely, and required resterilisation.

Again, in a small number of the early cases in which a bacterial standard of "two per field" was adopted, the sutures yielded results much inferior to the later ones.

The more nearly the wound approaches to "bacteriological sterility," the more certain is a good result with primary union, and in many of our sutures films taken just before suture showed no organisms visible in twenty or thirty fields. These cases never failed to result in absolute primary union.

Standards for Secondary Suture—1. *Clinical.*—The clinical side must not be neglected. The wound must be free from conditions surgically contra-indicating closure, such as presence of dead bone, spread of infection to unexposed parts of bone, joints, etc. It must be remembered that smear counts show only the extent of infection in the part or parts of the wound from which the smears were made; and while there is seldom any fallacy if the rule be followed of taking smears always from the parts of the wound which appear most dirty, yet in a number of cases unskilled smear-taking may give erroneous results. This is most likely to be the case when a large amount of blood is taken up with the wound exudate, and it is important to take the smear from the most suspicious part of the wound—seat of fracture, base of sinus, bottom of depression, or whatever it may be—without making the granulation tissue bleed more than is unavoidable. If smears are spoilt in this way, they should be taken again at the next dressing.

In nearly all cases, when the bacteriological criterion is satisfied, the wound looks clean, although the converse is not nearly so true and cannot be quite relied upon, even after a long experience.

2. *Bacteriological.*—The procedure is as follows: When the wound presents a healthy red and dry granulating surface, or in other respects has every appearance of being clean enough for suture, as judged by experience, a smear is made in the manner described (p. 104) from the most suspicious part of the wound, and stained with carbol-methylene blue. The film is made immediately after the dressings are removed from the wound, and before any of the exudate is washed away from the wound. If the result be satisfactory, the examination is repeated on the following day, and if still satisfactory the wound is passed for secondary suture. An unsatisfactory result after a reasonable time for sterilisation may suggest to the surgeon a possible hidden focus of sepsis—*e.g.*, sequestrum, foreign body, or some fault in the surgery of the wound or technique of the dressing. In these cases the bacteriological examination should be repeated after a few days.

The bacteriological standard which we have found satisfactory is the presence in two successive daily films, prepared as above, of the following features:

(*a*) The average number of organisms not exceeding 0·4 per field (two per five fields), and in no case including large, stout, Gram-positive bacilli, which are likely to be *B. perfringens*. The presence of this organism is an absolute contra-indication even in the absence of clinical signs of gas infection.
(*b*) The polynuclear leucocytes healthy and preferably not too abundant.
(*c*) The macrophages relatively numerous.

When these criteria are satisfied, the healing of the secondary suture by primary union is almost a mathematically certain result.

In our series of 600 secondary sutures, including a large proportion of fractures, and also a certain number of experimental cases, there were just over 90 per cent. of primary unions. In the remaining 10 per cent. various degrees of gaping occurred, from ¼ inch to 3 inches in width. Complete break down of the wound occurred in not more than eight cases. Resuture was performed in four cases.

Reactions following Secondary Suture.—Where sterilisation of wounds has proceeded uninterruptedly and has been completed, according to the above standards, within two or three weeks, the local and general reactions following upon the operation of secondary suture are very slight or absent altogether. In the larger wounds, there may be slight redness and swelling around the wound, and the temperature may be raised a degree or two for one or two days. In most cases there is no reaction at all. In cases of delayed sterilisation, however, it has been very constantly observed that more severe local and general reactions follow the operation, and not infrequently the sutured wound may appear to be on the point of breaking down two or three days after the operation There may be

local redness, tenderness, swelling, and exudation, and the temperature may reach 102° F. on the evening following operation. In most cases the whole inflammatory disturbance settles within four to six days, and the temperature is rarely elevated for more than two or three days. Suppuration hardly ever occurs, provided the wound be not reopened.

In these cases of delayed sterilisation there is a considerable thickness of granulation tissue in the apposed wound surfaces. In the rapidly sterilised wounds the amount of granulation tissue formed is minimal. We believe that it is the thickness of granulation tissue in the wound rather than true sepsis which gives rise to the reactions. When the two granulating surfaces are brought together, enclosing a small number of organisms, some of which are, however, deeply embedded in the walls, a free exudation of lymph and leucocytes naturally occurs from this large amount of highly vascularised tissue. The infection is, however, practically never sufficient to cause death of the leucocytes and pus-formation ; but it usually becomes rapidly subdued, diapedesis of the leucocytes back into the circulation takes place, and the reaction subsides.

The important practical point, therefore, to be learned from such cases is that *these reactions should be expected in the case of wounds in which sterilisation has been delayed; that the stitches should not be removed, unless with very good reason, and that the reaction should be aided by the application of heat.* We have found these measures adequate in the majority of these rather troublesome cases, and gaping of any considerable extent rarely occurs. The resulting scar, however, is never so neat and associated with so little loss of function as in the case of rapidly sterilised wounds.

Secondary Suture over Bone.—Compound fractures and amputation stumps are no less suitable for secondary suture than flesh wounds. Especial care must be taken that the requisite degree of sterilisation has been reached before suture is attempted. The clinical and bacteriological standards are the same in all cases. In a series of 600 secondary sutures more than 200 were sutures over bone, and primary union was obtained in almost 90 per cent. of these sutures. It is astonishing how well these bone cases can be sutured after sterilisation by the Carrel-Dakin method. The end-results are hardly less favourable than those obtained with flesh wounds.

Partial Suture.—This is a convenient operation in certain types of wound in which there is a large fleshy portion which is easily sterilised, together with a bony or ligamentous portion which is more resistant to sterilisation. In such cases it is often desirable to suture the fleshy portion as soon as it reaches the condition of "clinical sterility," in order to avoid excessive granulation-tissue formation and subsequent scarring in a large wound. The bony or ligamentous part is not, however, at that time sufficiently sterilised for secondary suture, and it becomes a question whether the wound should be left until the whole is "sterilised," or whether the fleshy portion should be sutured at once and the other portion left

open. The latter procedure can safely be followed in a large number of cases. After the suture of the fleshy part of the wound, sterilisation of the other part is continued until it, in turn, is ready for suture. A typical example is the following:

Pte. H—— was wounded in the shoulder and upper arm by a piece of shrapnel on May 8, 1917. Parts of the head of the humerus and acromio-clavicular articulation were blown away, exposing the shoulder-joint and cancellous bone of the head of the humerus. The missile had passed along the length of the upper arm, producing a long narrow flesh wound in deltoid, biceps, and triceps, almost as far as the elbow. The wound was excised and treated with Carrel tubes. The fleshy part was found to be "clinically sterile" on the fourteenth day, while the bony part of the wound still gave a smear count of twenty per field. The fleshy part was sutured, and Carrel tubes were left in the upper bony part, which became ready for suture in its turn on the twenty-fourth day. The suture was then completed over the bone. Both sutures resulted in primary union. The preliminary partial suture did not in any way interfere with the sterilisation of the bony portion, nor was it itself affected by that sterilisation.

VI. The Local Infection in Wounds of Serous Cavities

Wounds involving the serous membranes, the peritoneum, pleuræ, meninges, and synovial membrane of joints, are fully considered in the chapters on these special regions. It is only necessary here to indicate in a general way how the local infection in serous membranes differs from that in the less highly specialised tissues, such as muscle and fascia.

The serous membranes, bathed in fluid and forming layers which line potential spaces, offer a much diminished mechanical resistance to the spread of well-established infection, in virtue of the ease with which infected fluid may pass along their surface. The mechanical resistance to the passage of fluid in serous cavities is much less than that in the denser tissue structures, and even considerably less than that in the areolar tissue spaces or the space between muscle fibre and sheath. If the spread of infection in any tissue is conveyed from point to point in the fluid which surrounds an inflammatory focus—and this seems to be the usual rule, and to hold even in the case of spreading gas gangrene (p. 156)—there is little wonder that infection may sometimes spread throughout serous membranes with great rapidity since the mechanical resistance offered to the passage of the fluid is overcome by a pressure little greater than zero. That such mechanical considerations largely determine the path of spread of infection is shown in the case of the knee-joint, where the spread from anterior to posterior pouches takes place, under the influence of gravity, not between the ends of the bones, but by a path of lesser resistance around the sides of the joint between the layers of synovial membrane. From the

mechanical point of view, therefore, these serous membranes are handicapped in dealing with infection.

On the other hand, the vital resistance of these membranes to infection is of a very highly specialised kind.

They are all rich in the two chief elements of the bodily defence—serum and phagocytes. They are, even under normal conditions, large lymphatic spaces, and at the slightest approach of infection they become flooded with the protective lymph. This is well known in the case of appendix abscess just prior to rupture, where the peritoneum becomes flooded with a protective non-infected fluid. We have observed the same phenomenon in the case of large sloughing dysenteric ulcers, where colotomy has been performed, when the ulcers appeared to be almost on the point of rupturing. The serous membranes have, then, the advantage of an immediate rally of normal agglutinins and other antibodies whenever the slightest infection appears.

Further, the phagocytes, in these serous fluids are especially numerous and active. The membranes are lined with endothelium, whose cells readily become separated off as the well-known actively phagocytic macrophages. There is thus a much greater preliminary supply of macrophages in this than in any other tissue, and the vital resistance to infection is correspondingly higher. Intraperitoneal injection of organisms into animals is usually less dangerous than subcutaneous or intravenous injection, unless the organisms be so virulent or the animal so susceptible that the channel of entry makes no difference. Peritoneal fluid removed soon after intraperitoneal injection of organisms shows a very active phagocytosis on the part of the macrophages. The phagocytic power of the serous membranes is, therefore, considerably higher than that of most of the other tissues.

A further element in the specialised defence of these membranes is the power of gluing themselves together which they all possess in common. This element of defence is more concerned with well-established infection, and is a later phenomenon designed to counteract or limit the mechanical ease of the spread of infected fluid which is associated with the anatomical structure of the membranes. The lymph, which is poured out in quantity, coagulates after some time, forming a plastic exudate which firmly binds for a time the two membranes together, at the points of apposition. This coagulated exudate may later be dissolved if the infection be sufficiently virulent, and it is then that the mechanical factor enters, and the infected fluid spreads widely and rapidly throughout the membrane. In many cases, however, the coagulated lymph forms a sufficiently strong barrier, and it becomes the basis of still stronger fibrous adhesions which completely wall off the infection, which may thus end in abscess-formation or may be overcome without such result.

The evidence derived from penetrating and perforating gunshot wounds of the serous cavities supports the theory that the serous membranes are all highly resistant to commencing infection. In abdominal

wounds with perforation of the gut the prognosis is remarkably good if the continuous supply of infecting organisms is stopped by early suture of the perforations. The peritoneum is well known to be capable of dealing with a large amount of fæcal infection, provided the source of supply be cut off. The pleural membranes also are resistant, but here the problem is usually complicated by the presence of a large amount of altered blood, which provides pabulum for the organisms and prevents ready access of the macrophages and lymph to them. In spite of this disadvantage, however, the majority of these hæmothorax cases remain sterile.

The meninges are resistant to pyogenic organisms in gunshot wounds of the brain. If the foreign body be removed and the dura mater sutured, the meninges can be trusted in most cases to overcome the infection which has been left behind. Even in suppurating encephalitis, although the path of entry has been through the meninges, there is often nothing more than a hyperæmia of the meninges without actual pus-formation. When purulent meningitis does occur, it is usually long delayed, often after days or weeks of purulent encephalitis, provided that the effects of intracerebral pressure have been counteracted by operation.

Joint and bursal synovial membranes reveal the same power of resisting commencing infection when they are put under favourable conditions. If absolute fixation of the knee-joint in the position of slight flexion be carried out with suture of the hole in the synovial membrane, and application of pressure-pads to prevent spread of infected fluid to dead spaces in the posterior pouches, the synovial membrane can deal with any of the ordinary bacteria of wounds, with the possible exception of *Streptococcus pyogenes*. The truth of this is borne out by the statistics of a large series of penetrating wounds of the knee-joint which we have treated (pp. 375, 380).

Lastly, the incidence of gas gangrene in the serous membranes throws further light on their resistant nature. Its incidence in gunshot wounds of these structures, except in the case of the pleuræ, is so rare as to be almost negligible. That the infection is there is beyond doubt, for *B. perfringens* and other anaerobes are not uncommonly cultivated from the exudates in penetrating wounds of serous cavities. The pleural cavity is a special case, on account of the blood which is present. Even here gas infection is often localised, and its commencement can be traced to the mass of altered blood.

The subsequent progress of infection in serous cavities, where the infection has not been left to be dealt with entirely by the membrane, but where the cavity has been opened, does not differ materially from that in the tissues generally. The Carrel-Dakin method has been successfully applied to all the joints and to at least the pleural cavity. The microscopic history of these wounds follows fairly closely the lines of the type description. Sloughing, granulating, dry, and sterile stages succeed one another, but there may be great variation in the length of these stages,

owing to the difficulty of obtaining free access of the hypochlorite solution to every part. Secondary suture, both of joints and pleuræ, has been successfully performed according to the principles already discussed.

The General Infection and Bodily Response

Toxæmia.—Every inflammatory focus is associated with some degree of toxic absorption, causing general systemic poisoning, or toxæmia. Toxæmia arising from infected wounds varies greatly in severity. The slighter forms may give rise to nothing more than slight general discomfort, or to mild symptoms such as loss of appetite and constipation. The temperature may not be raised more than half a degree. On the other hand, toxæmia may assume extremely grave forms, simulating closely the various septicæmias.

The two chief varieties of toxæmia following infected wounds are—

(1) Toxæmia due to pyogenic organisms.
(2) Gas-gangrene toxæmia.

(1) *Toxæmia due to Pyogenic Organisms* occurs in all cases during the stage of inflammation, and, during the stage of suppuration, when pus is confined under pressure. In the case of an excised wound undergoing treatment by the Carrel-Dakin method, the temperature is not infrequently raised during the earlier stages of the sterilisation process, and malaise, weakness, wasting, and other well-known symptoms of toxæmia, may be present in greater or lesser degree. This is due in most cases to incomplete excision of the wound, leaving minute diverticula in the walls. Into these diverticula the hypochlorite solution does not penetrate, and small quantities of pus therefore become confined within them under some pressure. The toxins produced in these spaces are not washed away from contact with the tissues, and absorption into the general circulation occurs. The more complete the excision of the wound the less is the toxic absorption, and the converse holds equally. In the ordinary cases the minute diverticula become obliterated by granulation tissue in the course of a few days, and the temperature falls and toxic symptoms cease. In exceptional cases, however, the mouth of a diverticulum may become closed, leaving pus confined within the tissue. Tracking of this pus between the tissue planes is then liable to occur, and localised collections of pus of varying extent may be formed in the neighbourhood of, or remote from, the wound. Such tracking pus and collections of pus not uncommonly take many days or even some weeks to localise themselves, and during all this time toxic absorption proceeds steadily. In such cases severe and prolonged toxæmia may be produced, and the temperature chart and general condition may closely resemble that of streptococcal or other septicæmia. In the earlier stages it is often very difficult to discriminate between the two conditions, but as time goes on the difference becomes more apparent. In severe

toxæmia there is swinging temperature, pallor, weakness, wasting, and there may be loss of appetite, constipation, etc. If the condition is prolonged, amyloid changes may occur in liver, spleen, kidneys, and intestine, with resulting hepatic or splenic enlargement, polyuria, or diarrhœa. Seldom are there seen, however, the more severe and characteristic symptoms of septicæmia, such as rigors, sweating, and rapid pulse, etc., and, the most important of all, the syndrome mentioned in connection with streptococcal septicæmia—namely, (1) dry furred tongue, (2) tremor, (3) tetanoid spasms. In the early stages, however, say during the first week of the condition, it is often impossible to tell whether a case is one of toxæmia or of septicæmia, and in all such cases, in view of the importance therapeutically of an exact diagnosis, it is desirable to have a blood culture performed (*vide* Septicæmia).

One case, with accompanying chart, may be quoted to illustrate these points.

Pte. R——: "Toxæmic Temperature" from Retained Pus

Pte. R——, R.F.C., was wounded by H.E. in the left leg and foot and left buttock on November 28, 1917. He sustained a compound fracture of left tibia and fibula. The wounds were excised and treated with Carrel's tubes. Twelve days after infliction of the wounds the temperature, which had been just above normal, became *high and intermittent.* The chart was not altogether like that of a streptococcal septicæmia (in which the temperature is usually *high and remittent, with occasional intermissions*). Moreover, his tongue was clean, his pulse good, and there was no tremor. A blood culture performed on two occasions, December 15 and 22, was in each case sterile. As he appeared to be going rapidly downhill, the foot was amputated on January 6, 1918. Dissection of the foot and ankle after amputation showed that the ankle-joint contained pus and had become ulcerated, and the inferior tibio-fibular articulation was sloughing.

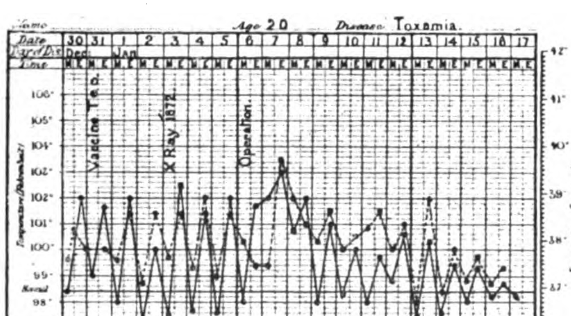


FIG. 33.

The astragalo-calcanean joint was also filled with pus. It is possible that early astragalectomy in this case would have saved the limb.

After amputation the intermittent character of the temperature chart

(toxæmia from retained pus) completely changed and the temperature gradually fell. Its rather slow fall was due to an ulcerative faucitis which occurred just after the operation. The latter part of the chart, showing high intermittent temperature and gradual fall to normal after the operation, is appended.

Another way in which severe toxæmia may arise is from the retention of pus within cavities such as joints. The knee-joint, on account of the multiplicity of its pouches, is the most likely of all to give rise to this condition. In most cases of penetrating wounds of the knee-joint the synovial membrane may be relied upon to subdue the infection if it be put under the proper conditions (p. 372). But in certain cases, especially where *Streptococcus pyogenes* is present, the inflammatory process proceeds to pus-formation, and unless each infected pouch be opened and freely irrigated, pus will be retained under pressure, and a severe toxæmia will occur. Such toxæmia is very apt to be followed by actual streptococcal septicæmia.

(2) *Gas-Gangrene Toxæmia* in its severer form is a very grave condition associated with the spreading type of gas gangrene in wounds. There is extreme prostration, an ashen pallor, jaundice, vomiting, and very rapid, feeble pulse. Hæmolysis of the blood may occur. The condition and its treatment are fully described in the chapter on "Gas Gangrene" (p. 164). It is apparently due to the absorption of powerful poisons formed by the disintegration of the protein molecule of tissue cells through the activity of the gas-forming bacilli. In certain cases it is followed by gas-gangrene septicæmia and pyæmia.

General Bodily Response in Toxæmia.—The nature of the toxins produced by bacteria growing in the tissues has been already considered (p. 99). They are substances allied to albumoses, formed either from the bacterial protein or the tissue protein. They attack tissue cells either before or after absorption into the circulation and the cells respond by producing specific antitoxins, which antagonise both bacteria and toxins, and this they do, apparently, in a considerable variety of ways (p. 100). The production of these antibodies, which is one of the main elements of the bodily defence, is dependent, on the one hand, on the stimulation of the tissue cells produced by auto-inoculations of toxin, and, on the other hand, on the vital activity or healthy character of these cells. The other element in the general bodily defence, the over-production of phagocytes, seems to depend upon chemiotactic influences from the septic focus, which are practically automatic, and the degree of this reaction is therefore most closely related to the degree of vital activity of the patient.

In order, then, to raise the level of a patient's general resistance to infection, it is possible to work along two distinct lines :

(1) Increase of the antitoxins through regulation of the toxin supply.
(2) Increase in number and potency of the antitoxins and of the phagocytes through improvement of the patient's physical condition.

Of these, (1) is concerned with vaccine and surgical therapy, and (2) with general treatment.

The importance of the latter has been already frequently noted, and a few words on the subject will suffice here. It is obvious that conditions such as fatigue, shock, hæmorrhage, and chronic diseases—*e.g.*, malaria—which are all common accompaniments of present-day war wounds, must have a deleterious effect on the vital activity of the patient's cells, on which is dependent antitoxin and phagocyte production. The prevention and treatment of these conditions is considered in the chapter on the "General Treatment of Wounds" (p. 238) and elsewhere. The influence of malaria in producing a chronic indolent granulating condition in the wounds of certain of those who suffer from the disease, as well as its influence in favouring certain more acute types of sepsis, such as erysipelas and cellulitis, is also indicated (pp. 215, 216). The harmful effects of a prolonged period in bed, with consequent interference with digestion and nutrition, must also be emphasised, and it should be noted that soldiers, as a class, are generally benefited by getting out of bed earlier in convalescence than may be applicable to the general public. Thus, in the case of compound fracture of the femur the patient is now, in the normal course of events, kept in bed not longer than three weeks, and is then made to move about on a walking splint until firm union and healing are obtained. The effect of such early ambulatory treatment is most marked in producing rapid elimination of toxæmia and infection, as well as rapid healing. Patients whose evening temperature has been constantly 99° to 100° F. often show a permanent fall to normal within one or two days of getting up on to the walking splint. In the same way, the early application of massage should be ordered, and early facilities for exercise and getting out into the open air given, wherever possible, in order to improve general nutrition. By attention to all these details, and by carrying out appropriate measures, much can be done to raise the general bodily resistance and, by so increasing the vital activity of the tissue cells, to bring about an increase in the number and power of the defensive elements.

With regard to (1) above, the regulation of the toxin-supply from an infected wound may be brought about by surgical and bacteriological means. The surgical measures are the general ones of excision of wounds, removal of foreign bodies, immobilisation, and antiseptic treatment. All of those measures are directed towards removing sources of gross toxin-production. Immobilisation is very potent, especially in the case of compound fractures and joints, in cutting down excessive and irregular auto-inoculations. Such auto-inoculations of toxin do the patient harm. The doses are unregulated, and they are not timed to act upon the anti-toxin-producing cells in such a way as to obtain the maximum response. When an animal is inoculated with a dose of toxin, there is, as Wright showed many years ago, a negative phase of variable duration during which the tissue cells are under the influence of the toxin, and the amount

of antitoxin in the blood is minimal. This is quickly succeeded by the positive phase, during which there is over-production of antitoxins and the bodily defences are at a high point. A second inoculation during the negative phase is very harmful to the animal, and may do lasting or permanent injury. A second inoculation during the positive phase, however, produces no harmful symptoms, provided the dose be not too great, for excess toxin is quickly neutralised by the abundant antitoxin. Moreover, the end-result is a further increase in the available amount of antitoxin. It follows that ill-timed or excessive auto-inoculations are harmful in their immediate and remote effects on the patient's general condition and reaction, and prejudice greatly his recovery from the infection. Nowhere, perhaps, in the range of medicine or surgery is the clinical evidence for the above pathological considerations so striking as in cases of active pulmonary tuberculosis. But they hold also in the case of infected gunshot wounds, and although auto-inoculations are in most wounds controlled by surgical means, there are certain wounds in which autogenous vaccines are helpful in producing the desired effect.

Vaccine Therapy in Wounds.—Autogenous vaccines may be used with good effect in the treatment of an infected wound. In the vast majority, however, they are now unnecessary, because of the rapid sterilisation that is effected by the Carrel-Dakin method of treatment. In wounds of the body generally the infected surfaces can be more or less completely exposed, and their sterilisation is then readily brought about through the agency of direct intermittent irrigation with hypochlorite, combined with the normal serological and phagocytic agencies. In most cases it is inconvenient and unnecessary as a routine measure to stimulate these agencies by employing autogenous vaccines. The method is too laborious for application to large numbers, and there is no evidence that it results in a more speedy average sterilisation of flesh wounds or of compound fractures than that which we obtained over a large series of cases without them—viz., eight to ten days for the former and two to four weeks for the latter. We have learned gradually that the more efficient the surgical technique, the less is the need for vaccines.

There still remain, however, certain types of wound in which the employment of autogenous vaccines is indicated as a useful adjunct to surgical measures.

Such types include the following :

1. Wounds in which the progress of sterilisation is unduly delayed.
2. Wounds in which access of the antiseptic to all infected parts is difficult or impossible.
3. Wounds complicated by septicæmia and pyæmia.

In the first two of these types (toxæmic as contrasted with septicæmic types), autogenous vaccines, while undoubtedly helpful, are often insufficient in themselves, without further surgical intervention, to bring

about the required rapid completion of the sterilisation process. In the third type, autogenous vaccines are clearly indicated and constitute often the only treatment which is of any avail.

1. Wounds in which the Progress of Sterilisation is Unduly Delayed.—Delayed sterilisation of wounds has been already considered (p. 114), and it has been emphasised how often this condition is due to inadequate surgical measures. There are cases, however—*e.g.*, in compound fracture of the femur—in which further surgical interference may be attended by risks of spread of infection to bone or to the general circulation. In such cases autogenous vaccines are helpful, and may be sufficient to achieve what is wanted.

Foreign Bodies.—If a foreign body be suspected to be the cause of the trouble, the wound should be opened up, and an effort made to remove it. Pieces of necrosed bone are generally best left until they sequestrate, and in such cases vaccines may aid the process.

Compound Fractures.—Where a compound fracture is excessively comminuted, there is often considerable difficulty in sterilising the wound. Vaccines are then useful, especially at the stage when the chief organism present in smears is *Streptococcus pyogenes.* This is the organism which is almost always predominant in these resistant cases after the first week or so. Where there is much loss of bone substance, with some necrosis of bone, and delay in sterilisation, vaccines are sometimes of value. But these are obstinate cases, and reinfection of the wound occurs very readily. If vaccines are given, they should be administered in large doses, since the acquired immunity of the patient against the offending organisms is of a high order, and he is usually entirely unaffected by small or even moderate doses of vaccine. In all such cases the commencing dose of streptococcus vaccine should not be less than ¼ slope, or approximately 1,000 million organisms.

Flesh Wounds.—Simple flesh wounds occasionally give rise to difficulty in sterilisation, for various reasons. Sometimes spread of infection occurs to joints, tendons, etc., and tracking of pus between the muscle planes. General surgical principles must be followed here, and if these fail, vaccines sometimes help to subdue the infection. At times the difficulty is due to sloughing of tough fascial structures such as the fascia lata, aponeurosis over erector spinæ, etc. It takes a considerable time for such sloughs to dissolve and separate, but they come away well in the end—say two weeks, or rather more—and it is very doubtful whether autogenous vaccines have any accelerating effect on the process.

Technique.—Again, as sometimes happens, the trouble may be found to be due to careless or inefficient application of the tubes or of the solution. The wound may then fail to become sterile, and may fall into a chronic indolent condition, with exuberant granulations containing little crypts and irregularities difficult to sterilise. Vaccines are not very suitable here, as there is often a considerable variety of organisms present. The best

treatment is to apply tubes and solution earnestly for a few days, and then to secondarily suture the wound, even though the bacterial standard be somewhat high. There may be a marked local reaction in such cases for a few days, but these wounds usually heal fairly well after suture.

General Reaction.—Sometimes the general reaction is poor, as in badly wounded and shocked men, or men suffering from malaria or other chronic disease. Vaccines are then of very doubtful value, for their whole therapeutic effect depends on the ability of the tissue cells to respond to stimulation, and in these cases this is precisely what is lacking. It is better here first to treat the underlying condition as vigorously as possible, and later, if the general condition improves, to resort to vaccines.

Type of Infection.—Of all the various kinds of wounds which come under this heading, it is those in which the routine smears detect a long chained streptococcus as the most abundant organism present, and in which some resistance is displayed to the ordinary rapid sterilisation by the Carrel-Dakin method, that are the most likely to be benefited by the exhibition of autogenous vaccines. This we have found to apply both to flesh wounds and to compound fractures. The immediate results are often striking, and the wounds may become very rapidly sterilised. In nearly all cases, however, if the delay in sterilisation proves to be due to gross fault in surgical technique, the vaccine is not sufficiently powerful to make up for such a defect, and the wound lapses back into its old state after some days. With increasing experience we have seen that the more efficient the surgery of the wound, the more likely is the infection to be subdued by the direct antiseptic treatment, and consequently the less is the need for vaccines. In this type of case vaccine treatment is always strictly the handmaid of surgery.

2. Wounds in which Access of the Antiseptic to All Infected Parts is Difficult or Impossible.—Under this heading is included infected foci in such tissues or organs as the brain, neck, chest, abdomen, and joints, where sufficiently wide incision to permit of thorough application of Carrel's tubes to the infected area is inapplicable.

Brain.—Where removal of the foreign body from the brain is unsuccessful or impossible, and also in certain other cases, the brain substance may become septic or gangrenous. The Carrel procedure is not applicable here, and as no vigorous direct antiseptic measures can be carried out, treatment by autogenous vaccines is strongly indicated. The organisms required for the preparation of the vaccine may be isolated either from the wound discharge or (better) from the cerebro-spinal fluid, if the latter be infected. These are all most serious cases, and we have not had any conspicuous success with vaccines.

Neck.—Wounds in close proximity to the important structures in the neck cannot, in some cases, be adequately irrigated, and in such cases, in view of the importance of securing rapid sterilisation, owing to the danger of secondary hæmorrhage, etc., autogenous vaccines should be administered.

This principle is applicable also to cases other than gunshot wounds. For example, in a severe case of Ludwig's angina, with much inflammatory œdema, after incision and evacuation of the pus, the toxæmic symptoms, as well as the severe and dangerous character of the local infection, still gave rise to anxiety. An autogenous vaccine made from the pus contained *B. coli*, streptococcus, and *Staphylococcus aureus*. The first dose of the vaccine was followed by a considerable local and general reaction, after which a very rapid and striking improvement took place. The infection became subdued almost immediately, and the wound was healed five days after the vaccine was given.

Chest.—In infected hæmothorax cases with thoracostomy performed, and in purulent mediastinitis and pericarditis it is difficult or impossible to secure irrigation of the whole infected surface, even if the Carrel procedure be applicable at all. An autogenous vaccine is then strongly indicated. In most infected hæmothorax cases with thoracostomy the outlook is good, provided that gas be rapidly overcome. But, nevertheless, vaccines should be employed in addition to local irrigation. In a number of these cases in which they were used by the authors, a more rapid elimination of the infection seemed to be achieved. Where, however, collections of pus or infected foreign bodies are shut in, vaccines are useless without surgical intervention, and this general rule has a wide application.

Abdomen.—Vaccine therapy is frequently indicated in gunshot wounds of the abdomen. The number of possible applications is very varied indeed. One example may be given—viz., a penetrating abdominal wound with subsequent development of cystitis.

Pte. T——, 9th Border Regiment, was wounded by H.E. on August 30, 1917. He sustained a penetrating abdominal wound, the wound of entry being in the right loin above the iliac crest. Laparotomy was performed next day at the casualty clearing station. No rupture of the gut was found, but surgical emphysema was present around the cæcum and ascending colon, up to the hepatic flexure. No foreign body was found in the abdomen. A drainage-tube was put through the loin wound down to the cæcum, the laparotomy incision being stitched up.

On September 10 purulent cystitis commenced ; no catheter had been passed prior to this.

On admission to the base hospital on September 20, the laparotomy wound was gaping superficially, and was closed by secondary suture on September 23. The urine contained a large amount of pus and had an acid reaction ; micturition was painful, and at the end of the act pure pus escaped from the urethra. The bladder was washed out daily with potassium permanganate solution, and a mixture of urotropin and acid sodium phosphate given by the mouth. Treatment on these lines for a fortnight yielded absolutely negative results. On October 5 the urine contained as much pus as ever, and the pain was in no way improved. A catheter specimen on October 3 yielded abundant *B. coli* and *Staphylococcus aureus*

on culture, and a vaccine prepared from these organisms was given on October 5.

The first dose of the vaccine (1 c.c.) contained $\frac{1}{15}$ slope *B. coli* and $\frac{1}{15}$ slope *Staphylococcus aureus*. Its injection was followed by slight local reaction, and by distinct improvement in his symptoms. The washing out of the bladder was entirely stopped from October 5. On October 8, 2 c.c. of the vaccine were injected, and this was followed by a slight local and general reaction. He had malaise for a day, and his temperature rose to 99·2° F. Micturition was now painless and the urine clear. A third injection of the vaccine (3 c.c.) was given on October 11, followed again by slight local and slight general reaction. Temperature rose to 99° F., and he vomited. Examination of the urine on October 13 showed it to be quite free from pus, and in every way normal. All urinary symptoms had by this time subsided, and the patient was up and very well. He was dismissed to the convalescent depot on October 24.

In the above case the result of autogenous vaccine treatment on an established chronic purulent cystitis was very striking.

Joints.—When penetrated joints are treated by the dry method (p. 369), the fluid aspirated from the joint may be utilised for the preparation of a vaccine. The knee-joint is the most important of this class. In most cases in which the infection is other than *Streptococcus pyogenes*, the infection in the knee-joint is subdued within a few days by the proper application of the dry method. Some infections, however, are more persistent, and it is desirable that the help afforded by autogenous vaccines should be utilised. Where joints are opened and treated by the Carrel-Dakin method, it is always advisable to aid the treatment by the use of vaccines, owing to the difficulty of securing that each and every part of the joint surfaces receive the antiseptic irrigations. In all cases in which *Streptococcus pyogenes* is the predominant organism vaccines should be used, for, in general, the results obtained with vaccines prepared from this organism are remarkably good.

3. Wounds complicated by Septicæmia and Pyæmia.—These are the cases *par excellence* for the exhibition of autogenous vaccines. They constitute valuable specific treatment of these diseases, some forms of which are usually otherwise hopeless.

The theory underlying the practice of vaccine therapy in septicæmia is still somewhat obscure. Vaccines were at first believed to be suitable only for chronic and localised infections where, owing to infected foci being shut off to some extent, an insufficient amount of toxin became available for stimulation of antitoxin-production, which was consequently less abundant than was necessary. It was easy then, to see that an extra subnoxious amount of toxin introduced artificially in a vaccine might be the means of stimulating an increased production of antitoxin, which would be absorbed into the blood with consequent beneficial effect upon the infected focus.

In toxæmic cases with irregular auto-inoculations it was thought possible to regularise and increase the production of antitoxin by the use of vaccines, and such proved to be the case. It was difficult to conceive, however, how vaccine therapy could be applied to acute cases of septicæmia, where the organisms and their toxins were constantly in the blood-stream.

More recently it has become recognised that antitoxin is produced mainly by the fixed tissue cells, and, in the case of a vaccine inoculation, by the cells which surround the site of injection. Thus it has been shown that if a dose of vaccine be split up into a number of parts, which are injected separately at different sites, the effect produced is very much greater than where the whole dose is injected in one place. It becomes clear, therefore, that the amount of toxin absorbed is not the all-important factor in the production of antitoxins, but that the direct access of the toxin to the largest number of tissue cells is the predominating consideration.

It seems, then, probable that in septicæmia the access of the toxins to the tissues is not sufficiently prolonged or complete to stimulate the production of sufficient antitoxins, and this may serve as a working hypothesis for the vaccine treatment of these conditions. Whatever the rationale of the treatment may be, its value in practice has now been abundantly proved, and there need be no hesitation in adopting it. Moreover, in certain cases where it is desired to produce the effect of a very large dose of vaccine, it is useful to divide the dose and inject it in a number of places.

The vaccine should, if possible, be *sensitised* by the addition to it, or the simultaneous injection with it, of an antiserum of high specific potency against the organism in question. It is not possible usually to obtain an antiserum immunised against the particular strain of the organisms producing the disease. A stock antiserum must, in most cases, be used. In the case of streptococcal septicæmia, a supply of polyvalent antistreptococcal serum is usually available, and should be injected in large doses (20 c.c. to 40 c.c.) just before each dose of vaccine. A larger dose of vaccine can then be tolerated, and, in addition, the dissolution of the organisms and liberation of the endotoxins is believed to be more speedy. In serious cases, like those of streptococcal septicæmia and pyæmia, sensitised autogenous vaccines should always be used, if possible.

The various forms of septicæmia or bacillæmia complicating wounds which the authors have met with are described below (p. 189). In the streptococcal type, which is very serious and often fatal, good results have been obtained in some cases. In one case, where the *Streptococcus pyogenes* was found in the blood, and where every symptom and sign pointed to a fatal issue, the patient was saved and cured by sensitised autogenous vaccine. In the same patient a large pyæmic abscess in the lung was similarly cured by a second autogenous vaccine. In septicæmia due to *Streptococcus fæcalis*, which is a much rarer condition, sensitised autogenous

vaccines are also indicated. In the very acute virulent form of streptococcal septicæmia death usually occurs before autogenous vaccine treatment can be instituted, and these are hopeless cases. One such case is described, with chart (p. 193). In the lasting form of streptococcal septicæmia, which is fortunately much the more common, there is plenty of time allowed both for the diagnosis of the condition and for vaccine treatment. These are the cases which may be expected to yield good results. The dose of vaccine should be a large one, and should be judged by its capacity to give a fair degree of local reaction (redness and swelling). A dose short of this is generally not fully efficient. A tentative commencing dose may be given of ¼ trypagar or brain-agar slope, a dose which usually works out at 750 to 1,000 million organisms.

In septicæmia or bacillæmia due to coliform organisms, the clinical course has, in our experience, been comparatively mild and short, averaging seven to nine days' fever, and in all such cases specific treatment has not been required.

In septicæmia due to gas-forming anaerobes—*e.g.*, *B. perfringens*—the outlook is very bad, and vaccines are inapplicable, since the bacilli, being spore-formers, cannot be killed at a low temperature or by a low concentration of antiseptics. In one such case which occurred in our experience the infection in the blood-stream was double, *B. perfringens* and *Streptococcus pyogenes*. In this case a vaccine made from the latter organism yielded almost magical results for a time, but was unable in the end to prevent the fatal issue (p. 204).

A case of septicæmia due to a diphtheroid organism has been reported to us as having run a severe and prolonged course, and having been cured within a few days after treatment by two doses of an autogenous vaccine. We have not met with this form of septicæmia.

Preparation of Autogenous Vaccines.—The technique of the preparation of autogenous vaccines is given in full in textbooks on bacteriology. The laboratories in the field, however, are often scantily equipped, and improvisation of all kinds of material must constantly be made. Electric power is seldom available, and the more elaborate laboratory contrivances cannot often be obtained. Further, the laboratories themselves are usually tents or huts or rooms in houses, and are anything but dustproof and windproof. Under such conditions it is often impossible to carry out the elaborate technique described in textbooks, and simple methods are welcomed.

The steps in the preparation of autogenous vaccines are as follows :

1. Obtain primary growths from the infected material. Time, twenty-four to forty-eight hours.
2. Obtain subcultures of all the possible pathogenic organisms, if necessary.
3. Emulsify the subcultures.
4. Enumerate (if necessary) and sterilise the emulsions.

5. Test for sterility.
6. Transfer appropriate amounts of each emulsion to vaccine bottles or phials and label.

Steps 3 to 6 should be accomplished within twenty-four hours.

Autogenous vaccines are prepared in two, three, or (rarely) four days, according to the conditions. If one organism only be obtained and primary growths are obtained on solid media, the vaccine can be ready for use within forty-eight hours. If several organisms are obtained and subcultures must be made to separate them, the vaccine takes three days to prepare. In cases where the primary growths are obtained in fluid media—*e.g.*, blood cultures—the vaccine is ready in three days if one organism be found, and in four days if two or more organisms be found. The latter is a rare event in the case of blood cultures.

In all cases, if there be particular urgency, the sterility test may without much risk be omitted, and the periods given can then all be shortened by twenty-four hours.

1 and 2. PRIMARY GROWTHS AND SUBCULTURES—*Culture Media.*—It is essential to have a rich nutrient medium on which copious growths may be obtained. Ordinary agar is not suitable for the delicately growing organisms, such as streptococcus and pneumococcus. Enriched protein media have usually been obtained by the addition of blood, serum, or ascitic fluid to agar. It is difficult, however, in dusty laboratories to keep such albuminous fluids, in quantity, sterile ; and they are somewhat inconvenient to work with, since the fluids must be added directly before use, and it is not possible to autoclave and store the completed media in a form immediately available for use. In place of such media we have used for routine vaccine work a medium composed of equal parts of trypsinised brain tissue and nutrient agar. This gives an opaque mixture, but it has powerful nutrient qualities, it is easily prepared, and it can be autoclaved and stored in its completed form. This medium readily supports the growths of such organisms as pneumococcus, meningococcus and gonococcus. It gives very copious grow^hs of staphylococcus, streptococcus, diphtheroid and coliform bacilli, and most of the other organisms which are met with in routine vaccine work on wounds. Vaccines prepared from this medium should be filtered through one layer of lint in order to remove particles of medium from the emulsion.

The other medium which we use for the preparation of vaccines is Gordon's trypagar (see p. 75). This is a more difficult medium to prepare, but it is well within range of accomplishment of even the smaller laboratories in the field. We have used horses' hearts in the preparation in place of bullocks' hearts, which were not obtainable. The serum which we have usually found it convenient to add to the medium before use is Burroughs and Wellcome's normal horse serum, No. 3, sterile phials of which are always readily obtainable. There is no preservative added to this serum.

On this medium luxuriant growths of streptococci, pneumococci, etc., are also obtained, and an additional advantage is that the medium is transparent, and colonies of the various organisms take on a more distinctive character and are more readily recognised than those on brain agar. The fact that serum has to be added to the medium before use makes it rather less convenient to use than brain agar. We have been accustomed to use trypagar for obtaining primary growths, especially where a considerable number of organisms are likely to be isolated, as in vaccines from sputum or highly infected pus. In such cases plates are preferably employed in the first instances, but as an alternative five or six slopes may be used. Subcultures are conveniently made on brain-agar slopes.

3. Emulsification of Subcultures.—The diluting fluid is carbol-saline solution (0·5 per cent. carbolic acid in normal saline). Varying amounts, from 2 to 5 c.c., are transferred by means of a sterile pipette to one or two of the brain-agar sloped growths of each organism. The amount varies according to the strength of the vaccine desired. The emulsion is made by rubbing up the growth with a platinum loop, and mixing well with the diluting fluid. The emulsion of each organism is then filtered through lint (if the brain-agar medium be used) into a sterile test-tube containing small particles of broken glass. The latter are made by breaking up a test-tube into small pieces in a mortar. Each of these test-tubes is then sealed off by drawing out the neck in a flame. A convenient flame for laboratory glass-blowing in the field is a painter's blow-lamp. This gives a flame hot enough for ordinary work. If such cannot be obtained a spirit Bunsen burner or even a Primus stove may be used. The emulsion is then shaken by hand for ten minutes or put in an electric shaker if this apparatus be available.

4. Enumeration and Sterilisation of the Emulsions.—The enumeration of vaccines is unnecessary as a routine measure in wound work.

It is sufficiently established that the effect produced by a vaccine, *ceteris paribus*, is proportional to the dose. The number of killed organisms, however, which is necessary to produce any appreciable alteration in the reaction is immense, in the case of the common organisms of wounds. The enumeration method is therefore unnecessarily delicate in routine work. Since large doses of vaccine are given (such as produce appreciable local reactions), it is found to be sufficiently accurate to estimate the dose as a fraction of a sloped culture. Thus, the commencing dose may be spoken of as $\frac{1}{4}$ slope or $\frac{1}{20}$ slope, and this means that the dose is equivalent to the fourth or twentieth part respectively of all the organisms in a twenty-four hours' sloped agar (or brain-agar) culture, the latter being made in a uniform way and providing a fairly accurate uniform standard. This method is quite sufficiently accurate for practical purposes, for the dosage of vaccines in wound therapy is tentative and dependent on the individual local reaction. It does not admit of exact standardisation, since the other factors, the type and virulence of the organisms, are so variable.

In routine work the emulsions in their sealed test-tubes are sterilised without enumeration. Sterilisation is best carried out by heat at a temperature of 60° C. for one hour, and this is sufficient in the majority of cases. If a vaccine water-bath regulated to 60° C. is not available, it can be readily improvised by using two or three tins one inside the other, each inner one being supported so that its bottom does not touch that of the outer. In this way a single or double water-jacketed chamber is formed. If a lid covered with felt be made for the apparatus, the latter can be readily kept at a uniform temperature by the occasional application and withdrawal of heat. In sterilising the tubes of emulsion, the whole tube should be kept completely immersed in the water, which should be maintained at a temperature of 60° C. for an hour.

If it be inconvenient to sterilise vaccines by heat, antiseptics may be used instead. The usual antiseptics employed are carbolic acid and formalin. In the former case, the diluent employed is 1 per cent. carbolic acid in normal saline, and in the latter case 1·2 per cent. formalin in normal saline. The sterility test is applied after the antiseptics have been allowed to act for an hour or two.

5. Sterility Test.—This is made by breaking off the sealed ends of the tubes containing the emulsions and inoculating an agar slope with a drop from each tube. No growth after twenty-four hours' incubation at 37° C. is sufficient evidence of sterility for practical purposes. Even if a growth be obtained after the above sterilisation, the organism is so attenuated that its injection is not followed by growth in the tissues.

6. Transference of Vaccine to Bottles or Phials.—The former method is more convenient in military practice. It is convenient to have a number of sterilised small rubber-capped bottles, each containing 5 c.c. carbol-saline solution. The bottles containing the diluent, and having cotton-wool stoppers, are sterilised in the autoclave. The rubber caps are boiled in lysol and slipped on to the neck of the bottles, after removal of the temporary cotton-wool stoppers. This manœuvre is accomplished by means of two pairs of sterilised forceps. The rubber caps are wired tightly to keep them in firm position, and finally covered over with a thin layer of paraffin wax.

The transference of the emulsion from the sealed tubes to the bottles is accomplished by means of a sterile syringe. The amount taken from each tube depends upon the strength of vaccine required. Thus, if a tube contains 4 c.c. emulsion, representing 1 slope of streptococcus, and if half of the emulsion (2 c.c.) be transferred to a bottle containing 5 c.c. diluent, the vaccine then contains $\frac{1}{2}$ slope of streptococcus in 7 c.c.—*i.e.*, 1 c.c. vaccine = $\frac{1}{14}$ slope streptococcus. The bottle is labelled, the strength of the vaccine being written in such terms as the above, and the amount recommended for the first dose is stated.

Dosage of Autogenous Vaccines.—It has been already stated that, for practical purposes in vaccine therapy in wounds, it is sufficient to state

the dose of vaccines in terms of fractions of an agar (or brain-agar) sloped culture, instead of in numbers of organisms.

In our own vaccines we have observed that approximately the average number of organisms in a twenty-four hours' brain-agar sloped culture is as follows :

1 brain-agar slope	Staphylococcus	= 10,000 to 15,000	million organisms.
"	*Streptococcus fæcalis*	= 3,000 to 4,000	" "
"	*Streptococcus pyogenes*	= 2,000 to 3,000	" "
"	*B. pyocyaneus*	= 15,000 to 18,000	" "
"	*B. coli*	= 12,000 to 15,000	" "

These enumerations were made by the direct method of counting the organisms in various dilutions of the emulsion tinged with gentian violet in a Thoma-Zeiss hæmocytometer. We consider this method much more accurate than that of comparative enumeration with red blood-corpuscles in a blood-film. The figures given above are not, however, standards, and must vary according to the individual technique of each worker.

The dose of the vaccine should be large enough to produce a fair degree of local reaction, with or wihout a mild general reaction. When no local reaction is produced, the dose is unnecessarily small and time is being wasted.

The determination of the first dose is a matter of experience. The correctness of a dose may be gauged by the amount of local and general reaction produced. After the first injection the doses are regulated according to the reactions produced by the previous one.

Since for every dose of toxin there is a proportionate over-production of antitoxins, the general scheme of increase of doses should roughly correspond to a geometrical progression. The common factors most generally useful are $\frac{3}{2}$ and 2.

In the former case, with a commencing dose of 1 c.c., the scale of doses would be 1 c.c., $\frac{3}{2}$ c.c., $\frac{9}{4}$ c.c., $\frac{27}{8}$ c.c., etc., and in the latter case 1 c.c., 2 c.c., 4 c.c., 8 c.c., etc.

If more than three or four doses are given, a more concentrated vaccine must be made up from the stock cultures, and the appropriate doses calculated.

The commencing doses which we have found most usually applicable in local infections with the following organisms are—

Staphylococcus—$\frac{1}{12}$ slope.
Streptococcus—$\frac{1}{10}$ slope.
B. coli—$\frac{1}{15}$ slope.

In general infections with streptococcus a dose of $\frac{1}{4}$ to $\frac{1}{2}$ slope may be given with impunity, especially if the vaccines be sensitised by the simultaneous injection of antistreptococcal serum.

Stock Vaccines cannot be recommended for wound work, owing to the number and variety of organisms and strains dealt with. It is desirable in connection with infections of special structures, such as joints,

chest, brain, blood, etc., to make complete aerobic cultivations, at least from the exudates or fluids, in order to determine the type of infection. In all these cases the cultures may be utilised for the preparation of vaccines, if necessary. In cases of delayed sterilisation in ordinary wounds, the required cultures can be specially made with very little trouble.

Stock vaccines are generally held to be of considerable use in superficial pyogenic skin affections—*e.g.*, furunculosis, acne, boils, etc. Even in such cases, however, we have had vastly superior results with autogenous vaccines.

When vaccines are used, they should be autogenous in every case, unless where their preparation is absolutely impossible. Even a crudely made autogenous vaccine is to be preferred to a stock one, and the injection of such is justified in serious conditions where vaccine therapy is indicated.

CHAPTER VII

GENERAL COMPLICATIONS OF WOUNDS

Gas Gangrene.

FOR years before the present war, emphysematous gangrene complicating civil wounds was so rare that it might truly be said to have been non-existent. During the South African Campaign it was so rare that writers have not referred to it, yet during the present war, both on the Western and Eastern fronts, it has been not only the most frequent, but also the gravest complication of gunshot wounds.

The present war has differed so far in many important respects from the South African Campaign. In the latter case fighting was for the most part taking place in the open and on virgin soil, the rifle was the chief weapon of offence and defence, and the army was constantly moving. To-day we are fighting over ground heavily fertilised by both animal and human excreta. Siege warfare, alternating with attacks and steady slow advances, has taken the place of fighting in the open. The stupendous weight of artillery employed on either side has been almost inconceivable; whilst trench mortars, hand and rifle grenades, bombs dropped by airmen, asphyxiating gases, flame, and the like, have all added to the terrors of the present campaign.

The degree of mutilation and tissue destruction shown in the present war wound is highly favourable to the life and proliferation of anaerobic bacteria. But this is not all. Just as important for the existence and rapid proliferation of these organisms in a wound is the general condition of the soldier at the time he is wounded. If his resistance to infection be lowered by fatigue, as was so often the case earlier in the war; if after receiving his wound he suffer from severe hæmorrhage and shock, then the ideal conditions exist not only for the proliferation of these organisms in the wound itself, but also for their rapid spread into neighbouring tissues.

It was distinctly noticeable that gas gangrene was not very prevalent amongst fresh troops that had gone direct into action, whereas it was almost universal in the case of tired troops that had, prior to action, undergone long spells in the trenches. Even the smallest and the most harmless-looking of wounds, such as small seton wounds, involving only the soft parts, have been complicated by gas gangrene in fatigued men.

Localised Gas Gangrene.—The rate of spread of the infection varies enormously. Thus in some wounds of great severity the infection may become localised. Gas, with its characteristic foul odour, exudes from the wound, yet there is no tendency to spread and the general condition of the patient is good. Cases of this kind, it is true, are usually those of wounds involving the soft parts only, but we have also seen localised gas infection where bone has been implicated. This local type of gas infection occurred chiefly in men who had gone fresh into action.

Slowly Spreading Gas Gangrene.—Again, the infection may spread slowly, and this has happened in wounds which have caused hæmorrhage and shock. Men so wounded, who have gone fresh into action, have had their resistance lowered for the time being by the hæmorrhage and shock occasioned by their wounds. It would seem, however, that they are not totally deprived of resistance, and early surgical measures have often sufficed to arrest the spread of infection, provided everything possible was also done to improve the general condition.

Gas Gangrene involving Single Muscles or Muscle Groups.—Infection has often confined itself to single muscles or groups of muscles. We have now seen many such cases both at the clearing station and at the base hospital. The muscles most frequently involved, in our experience, have been the gluteus maximus, the gastrocnemii, and certain of the quadriceps group of the thigh. We have, however, seen cases in which such muscles as the sartorius and the biceps brachialis have been singled out.

Fulminating Gas Gangrene.—In contrast to the fore-mentioned is the fulminating type. Here it would appear that either the individual powers of resistance are nil or the infection is of a more severe type. There is strong presumptive evidence in favour of the former view, for others wounded on the same ground and during the same engagement have shown either the limited or the slowly spreading variety of infection.

The rate of spread of infection in true fulminating gas gangrene is wellnigh incredible, and the appearance of its victims almost beyond description. One or two examples will suffice to illustrate this :

After the battle of —— there were many wounded lying out both in No Man's Land and in the blind ends of certain listening saps. Though only a comparatively short time—eight hours or so—had elapsed since the receipt of their wounds, most of them were either dying or dead. Of the dying who were brought in, but few lived more than an hour or two. Some of these men, hit in the lower extremity only eight hours previously, were gangrenous to the umbilicus, while others hit in the arm were gangrenous up to and beyond the corresponding nipple. They presented a typical cyanotic colour about the lips and an ashen appearance about the face, while the eyes were bright and watery. Mercifully, their end was both rapid and painless, and they were buried in the line.

Some of the dead in the ends of these saps had for military reasons to

be left, and one of us had the opportunity of seeing their condition within twenty-four hours of being wounded. They were one bloated gangrenous mass. So rapidly had the swelling appeared and so extensive was its nature that the tunic, trousers, and even in one or two cases the boots, were burst open, and through the rents protruded the familiar greenish-black swollen and blebbed skin. Nor was this all, for the periscope on the following dawn revealed the bodies of many others in a similar condition.

It is a strange fact, but nevertheless true, that on the following night, when the few who survived were rescued, the majority of the living were those who had sustained wounds of the abdomen and chest; and considering what they had gone through their condition was remarkably good. In not one of these penetrating abdominal wounds that were rescued alive was there any trace of gas gangrene. Whether or not the peritoneal cavity can better resist this infection is an open question, but on this particular occasion it was a very noticeable point.

Another instance of rapid onset may be quoted. In a certain part of the line a man wounded in the thigh was brought to the regimental aid-post, where his wound (one of the penetrating variety) was dressed by one of us. We could not move him owing to heavy gun-fire which was then going on. After one hour the orderly reported that the man was in much pain. On inspecting his wounded limb, it was found that the bandage, at first loosely applied, was now very tight and the limb was swollen. The bandage was reapplied loosely. One hour later—that is, two hours after the wound—the orderly again reported that the man's limb was very swollen and getting discoloured. An inspection proved that he was right. The wounded man looked exceedingly ill and was feeling sick. This was a typical case of fulminating gas gangrene, and the limb was immediately amputated This latter procedure undoubtedly saved the man's life, and he reached England safely.

This example is only one out of many that we saw in the line, and although we were able to evacuate some of them, yet there were a number in which immediate amputation had to be carried out. In all amputations, performed in the line as well as those performed at the field ambulance or casualty clearing stations, the same typical yellowish-green gelatinous substance was present in all the connective-tissue planes. In such cases the whole limb had become involved, and not isolated groups of muscles; hence it struck us that the term "massive gas gangrene" was suitable and expressive of this condition.

Another very dangerous wound from a gas-gangrene point of view is a penetrating wound of the back, where the missile, with its concomitant piece of clothing, comes to rest just behind the peritoneum. In such cases a retroperitoneal hæmatoma results; the wound of entry, by contraction or herniation of the muscles of the back, becomes closed; and the most ideal conditions result for the life and proliferation of the gas-gangrene bacillus.

These patients arrive at the casualty clearing stations suffering with acute abdominal symptoms, due no doubt to pressure exerted by the gas or blood-clot on the posterior parietal peritoneum and the retroperitoneal nerve plexuses. Laparotomy has in many cases been performed and the abdominal wall subsequently closed. Such a procedure is followed by the rapid appearance of gas gangrene in the abdominal incision, and this condition spreads with alarming rapidity over the entire anterior abdominal wall, and soon causes death.

One case out of a number we can call to mind is that of a wounded German who had been hit in the back by a piece of high explosive during the Somme offensive. He was admitted to the casualty clearing station within eighteen hours of his being wounded, and was operated upon by one of us, as he presented acute abdominal symptoms with persistent vomiting. No damage to the gut had occurred and the posterior peritoneum was intact, but there was present an extensive retroperitoneal hæmatoma. The abdomen was closed and the piece of high explosive with clothing and blood-clot were removed from the wound in his back, the wound being left widely open. Four hours later the whole of the anterior abdominal wall was brick red and blebbed, and resembled in appearance a cooked ham. He was delirious and restless, and died two hours later of acute gas-gangrene toxæmia.

In this case, as in other similar cases, the infection had travelled forwards from the back in the retroperitoneal tissues to the anterior abdominal wall. Thence through the laparotomy incision it had found its way into the subcutaneous fascia of the abdominal wall, and had spread here with lightning rapidity.

These few cases were a lesson, because in all such wounds of the back giving rise to acute abdominal symptoms it is a golden rule to have an X-ray taken first, and when the position of the missile and its depth are known it should be removed without delay. At the same time all blood-clot should be cleared out and the wound of entry excised and enlarged. In a large number of these cases the missile will be found to be extra-peritoneal, and the prognosis is good if the missile and clot be removed at once.

Gas Gangrene and Serous Cavities.—It is an interesting fact that a piece of missile with its concomitant piece of clothing, when once it has entered the peritoneal cavity, very rarely gives rise to gas gangrene. In only one such case have we seen gas gangrene occur, and this out of a large number. This particular case was that of an officer who had been hit in the buttock, the missile entering the right iliac fossa external to the cæcum, and lodging there. A space was shut off, and when the abdomen was opened, broken-down blood-clot and gas escaped. The gut was uninjured, and *B. perfringens* was isolated from the discharge. It would seem that the peritoneum possesses a resisting power to the gas-gangrene bacillus of a higher degree than that of other tissues, and this is borne out by the

findings in the wounded who were still surviving after the battle of —— already alluded to.

It is of interest that gas gangrene is rarely seen in wounds of joint cavities in which the bones entering into the formation of the joint have not been damaged. In many cases we have extracted pieces of missile with clothing from joint cavities, especially the knee-joint, and such cases have never shown gas infection.

One case that particularly comes to mind is that of a sapper who was wounded in several places with a high-explosive shell. In all his wounds, except one, which penetrated the right knee-joint, there was gas infection. The wounds were excised and the foreign bodies extracted. The knee-joint was next dealt with, and a piece of high explosive and clothing were removed. There was no gas present in the joint, and he made a good recovery.

In the pleural cavities, however, gas gangrene under certain conditions seems to flourish, and there is probably an explanation for this. Most wounds of the lung are complicated by hæmothorax, the blood of which may often harbour infection. Such material constitutes ideal pabulum for anaerobic bacteria. We have never seen gas gangrene occur in a true case of pneumothorax.

It would appear, then, that serous cavities possess a higher power of dealing with anaerobic bacteria and preventing their growth.

Gas-Gangrene Infection of Brain.—The brain has on several occasions been the site of gas-gangrene infection. In a number of trephine operations performed by us, gas, with an objectionable and very characteristic odour, has issued from the perforation in the dura mater, and in some cases, although gas was present, the patient has before operation shown no symptoms beyond those of headache and perhaps a monoplegia. Recovery in the majority of these cases has been complete in so far as they could be observed up to the time of leaving hospital (usually ten weeks), and thus we must conclude that gas gangrene in these cases is of the limited type. *B. perfringens* was isolated from the discharge in all these cases.

We have seen a few instances, however, of massive gas gangrene of the brain, and it is surprising how long a man can live with this condition. We may quote one case as an example.

A German from the 162nd Regiment was struck over the head with a piece of iron. On admission to the casualty clearing station it was found that half of the calvarium had been battered in and a large piece of scalp was missing. He was perfectly conscious and rational, but was completely paralysed on one side. He was taken to the theatre, where it was found necessary to remove large quantities of diseased bone. The dura was badly torn, and the exposed brain was in an advanced condition of gas gangrene. The smell was of the characteristically offensive kind which is so typical of gas infection of the brain. The brain was covered with a dressing, as the scalp deficiency was too great to allow of its being covered

with scalp tissue. This man lived for five days and was conscious almost to the last, although each day large portions of the broken-down gangrenous brain were being removed in the dressing. This was not an isolated case, but one of a few. In scalp wounds uncomplicated by fracture of the skull, and in wounds involving the soft structures of the face, gas gangrene is an extremely rare complication. This is perhaps explained by the liberal blood-supply of these parts.

Gas Gangrene and Maggots.—It is said that everything possessing life serves some useful purpose. Can this be said of the domestic fly? We know that these creatures convey infection, and are justly looked upon as potential dangers to society. Every effort has been made to exterminate them as far as possible in the present war, and such efforts have not been in vain, for the numbers of flies both on the Eastern and Western fronts have, on the whole, been kept well within the limits of toleration. We have already stated that flies are a source of infection to wounds, but can any useful rôle be ascribed to the fly as far as wounds are concerned? In order to frame an answer to this question we can only speak of what we have actually seen.

During the Somme offensive in 1916 many wounds of a very serious nature arrived at the casualty clearing stations infested with maggots. These maggots were of two varieties, the small and the large. Whichever type of maggot was present, the salient fact stood out that maggots and gas gangrene did not exist together in the same wound. From the same regiment during the same action wounded men arrived, some suffering from a severe gas-gangrenous infection of their wounds, whilst others who were fly-blown showed no gas infection.

Again, at the clearing station some grossly infected gangrenous wounds were put outside the marquees, partly for their own benefit and partly for the benefit of those lying in the same tent. To a few of these wounds flies gained access in spite of all preventive measures. The wounds became fly-blown, and with the appearance of the maggots was associated the disappearance of the gas infection and the immediate improvement of the individuals concerned.

Exactly the same phenomenon has been observed in the Eastern theatre. An explanation of this we do not venture to suggest, but still the fact remains, and we have been concerned in so many of these cases, that we far prefer to see and treat a wound that is alive with maggots than a wound complicated with severe gas gangrene, for the former cases have all done remarkably well.

Maggots appear to stay in a wound only so long as there is dead tissue present for them to live upon, and they do not seem to exert any harmful effect on living tissues.

Maggot-infested wounds are most commonly seen in the case of men who have been lying out with their wounds uncovered. By the time such men reach the casualty clearing station it is usually too late to perform

wound excision, and under these circumstances the best treatment is slow, continuous irrigation with normal saline solution. We are of opinion that at such a stage it is unwise to destroy maggots, but better to let them continue their existence until they have digested all dead tissue, since patients do not seem to suffer, but rather benefit by their presence at this particular stage.

We have already quoted cases in which gas-gangrene infection of wounded tissues has subsided with the appearance of maggots. We can also quote cases to prove the converse.

A good instance is that of Pte. ——, 5th West Yorks Regiment, who was severely wounded in the right leg. Both bones of the leg were fractured and comminuted, and the wound was literally crawling with maggots. There was no active gas-gangrene infection present. The maggots were washed away with 1 in 20 carbolic acid. Upon their disappearance from the wound gas-gangrene infection set in. This happened on more than one occasion, and is, we think, further proof that these two conditions rarely, if ever, coexist in a wound.

Ætiology

The causes of gas gangrene in wounds have already in great part been referred to, both in the present chapter and in that on the "Bacteria of Wounds" (p. 65). It is desirable, however, to summarise them here. In the ætiology of gas gangrene predisposing causes and exciting causes occupy an equally important place. In this probably more than in any other disease is the combination of causes absolutely essential. In the absence of predisposing causes, the exciting causes—namely, the anaerobes which are in almost every wound—are in every case impotent. The converse, of course, holds equally.

The predisposing causes comprise the following :

1. Gross local tissue injury.
2. Absence of oxygen at the site of initiation.
3. Presence of multiple infection.
4. Presence of devitalising general conditions, especially *fatigue*, *shock*, and *hæmorrhage*.

1. Gross Local Tissue Injury.—As a general rule there is no type of tissue injury so favourable to the onset of gas gangrene as that produced in gunshot wounds, especially in those due to modern heavy and high-velocity projectiles, such as *high explosive*, *trench-mortar shells*, *bombs*, etc. That this is so is apparent from the fact that gas gangrene has been such a very rare event in connection with any injuries other than the wounds of the present war. What are the peculiar characteristics of this tissue injury which render the wound so liable to gas infection ? They are (*a*) the fact that muscle is so often one of the tissues involved, and (*b*) the condition of "stupor" which is commonly produced in those muscles.

In almost all wounds, except mere scratches and abrasions, muscle is involved, and, especially in shell and bomb wounds, it is so devitalised by the damage as to be the equivalent of dead tissue so far as the saprophytic anaerobic organisms are concerned. Reference has already been made in earlier chapters to the state of "muscle stupor" which is so common in the immediate neighbourhood of modern wounds—a state in which such muscle does not bleed, and does not contract when stimulated.

Muscle in this condition has no powers of vital resistance. It is for the time being a mere dead mass of organic matter which is from the chemical point of view an inert and rich accumulation of muscle sugar and protein. The muscle sugar or glucose is a substance most readily fermentable, and no resistance is offered to agents which endeavour to ferment it. Hence a *carte blanche* is given to any sugar-splitting anaerobes which may, and usually do, chance to be present in the wound ; they have a rich storehouse of suitable food to luxuriate in, and nothing to prevent them doing so. They begin, therefore, to develop with enormous rapidity at the expense of tissue, and once their growth has become established, they have a way of their own of providing for the continuance of their growth and the spread of the gangrenous process. This end they are able to achieve in a considerable proportion of cases, although in many the spread is arrested.

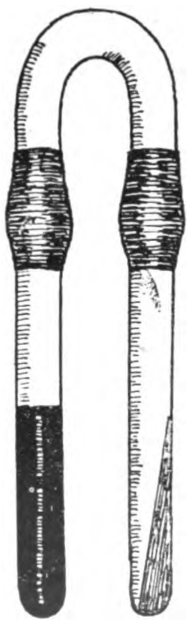
The spread of the gangrenous process appears to be aided by another characteristic of the muscle injury—namely, the microscopic separation of the muscle fibres and fibrillæ which may occur for some distance above and below the penetrated part of the muscle immediately on being hit by modern missiles. This point will be referred to later in more detail.

2. Absence of Oxygen at the Site of Initiation of Gas Gangrene.—Absence of oxygen is essential for the growth and development of anaerobic organisms. It is a condition brought about in recent wounds by two factors—(*a*) Muscle œdema, and (*b*) aerobic organisms.

(*a*) The muscle swelling or œdema which supervenes within an hour or two of the infliction of the wound has been elsewhere described. This swelling tends to obliterate rapidly the communications between the wound interior and the open air. If the wound of entry be small, the muscle often herniates through it, completely cutting off air entry into the wound surface. But even if this complete exclusion of air be not brought about, the irregularities of the walls and floor of the wound are such that the muscle swelling must often succeed in rendering little spaces and cavities air-tight, and by absorption of oxygen such spaces soon become oxygen-free. These spaces are the sites of initiation of the gas-gangrene process (see Plate II.).

(*b*) The second factor which tends to produce absence of oxygen in wounds, and especially in air-tight spaces in wounds, is the presence of aerobic organisms. These are practically always introduced along with the anaerobes. They grow readily in all kinds of wounds, and during

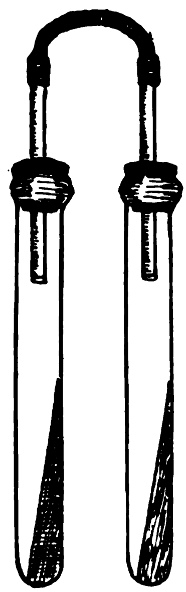
their growth absorb oxygen greedily. This can be experimentally shown in the laboratory by culturing aerobes along with anaerobes in an air-tight apparatus where the amount of air is limited. For example, if two test-tubes of culture medium be joined by a U-shaped rubber tube and a vigorous aerobe such as *B. subtilis* sown on one medium, and an anaerobe on the other medium, the oxygen-absorption produced by the aerobe is in itself sufficient to allow the anaerobe to develop. The oxygen-absorption in such an apparatus is almost as great as would be produced if a solu-



A B

FIG. 34.—Apparatus for the growth of anaerobes.

Tube *A* contains a solution of pyrogallate of potash ; tube *B* contains the medium for the culture of anaerobes. Tubes *A* and *B* are connected with sterile tubing.



A. B

FIG. 35.—Apparatus for the growth of anaerobes.

Tube *A* contains a vigorous culture of *B. subtilis;* tube *B* contains an anaerobe.

tion of pyrogallate of potash were substituted for the aerobic culture in the second tube.

Hence the presence of aerobic organisms appears to favour strongly the absence of oxygen in closed tissue spaces, and thus indirectly favours the onset of gas gangrene.

3. PRESENCE OF MULTIPLE INFECTION.—The type of multiple infection which is so favourable to gas-gangrene initiation is a combined aerobic and anaerobic infection. Such has often been proved to be present in 70 or 80 per cent. of all war wounds. The aerobes act not only by

absorbing oxygen, as has been already explained, but are also symbiotic in two other ways :

(*a*) By their toxic action, whereby they further devitalise the tissues ; and

(*b*) By taking up the attention of any polymorphonuclear leucocytes or other phagocytes which may gain access to the site of activity.

With regard to (*a*), it is to be remembered that the causal anaerobes of gas gangrene have no power of growing in healthy, active, living tissue, and that anything which produces a local devitalisation of tissue, such as the toxins of aerobes, has a most powerful influence in aiding the onset of gangrene. This point has been proved many times by animal inoculations. We may, in particular, quote those performed by Dean and Mouat* with strains of *B. aerogenes capsulatus* (*B. perfringens*) and of *B. œdematis maligni* (*B. sporogenes*), which they injected into guinea-pigs. Their conclusions were as follows :

(1) The subcutaneous injection of pure strains does not, as a rule, produce any sign or symptom of disease.

(2) If the tissues are damaged by a parasitic micro-organism (*Staphylococcus aureus* was used), foreign body, or other irritant, the introduction of *B. aerogenes capsulatus* or *B. œdematis maligni* may, in a comparatively small number of cases, lead to local gangrene and the death of the animal.

Tissier in experiments already quoted (p. 51) goes further, and finds that if the tissue into which the animal injections are made be damaged, as in wounds, gangrene can be produced in practically every case by injection of aerobic with anaerobic cultures.

Further, the more virulent the aerobe which is associated with the anaerobe in these injections, the more quickly is the death of the animal produced. He finds that the *Streptococcus pyogenes* is the aerobe which favours the greatest degree of anaerobic activity. This is of the greatest interest and importance in view of the fact that the commonest combination of aerobe and anaerobe in wounds is a streptococcus and *B. perfringens*. The practical universality of mixed aerobic and anaerobic infection in gangrenous wounds points also to the importance of such symbiosis. The streptococcus is well known to be one of the most harmful aerobes to tissue in a local or spreading inflammation, and it seems probable that its local toxic and devitalising action is a factor of great importance in determining the onset of gas gangrene.

With regard to (*b*) another aspect of the symbiosis of aerobic and anaerobic bacteria in wounds is brought into view. It is the fact that anything which prevents in some degree phagocytosis of anaerobes aids their growth. In this connection Tissier's further observations are important.

* *Journal of R.A.M.C.*, March, 1916.

He found that *Vibrion septique*, harmless in a dose of 2 c.c. of a liquid culture if alone, when mixed with *Staphylococcus albus* kills a guinea-pig with damaged tissues in twenty hours, and when associated with *Staphylococcus albus* and *B. mesentericus fuscus* kills in six hours.

That the presence of a harmless organism like *B. mesentericus* should make such a great difference to the result is a fact of considerable interest and importance. *B. mesentericus*, when injected alone into animals, produces practically no effect, and is rapidly removed by phagocytes. Now, it is well established by numerous observations on non-gangrenous wounds containing anaerobes, and also on wounds in which gas gangrene is spreading, that anaerobes are very readily phagocyted by the polynuclears and macrophages, but that in spreading gas gangrene the process may be so rapid that these organisms rapidly outdistance the phagocytes. These facts would appear, then, to suggest that primary phagocytosis of the anaerobes (which is, after all, merely a phase of healthy tissue reaction) is of great importance in preventing the onset of gas gangrene. If this be so, it seems to suggest a possible explanation of the experiments with *B. mesentericus*—namely, that the latter organism, by attracting to itself the available polynuclear phagocytes, thereby leaves the anaerobe more free to establish itself. If such be the case with *B. mesentericus*, it must be still more true of more virulent aerobes. The theory further accords with the well-known fact that multiple mixed infection is the rule in gangrenous wounds, and it suggests another way in which the aerobes in wounds foster the activity of the anaerobes.

4. Presence of Devitalising General Conditions, especially Fatigue, Shock, and Hæmorrhage.—The influence of these conditions appears to be all-important in determining the relative frequency of gas gangrene in a series of wounded men, and also its degree of severity. This point has been previously dealt with, and there remains to be added the experience gained during fighting periods and during quiet times on this front. In quiet times, when occasional men are hit by shell fire while doing their normal rounds of duty in the trenches, gas gangrene is quite a rare complication of wounds. In two large rushes of casualties which occurred, however, after long and arduous artillery and other military preparations involving for the men much night work, with excitement, loss of sleep, hard physical work, and finally the exacting work of uphill fighting in the open, the great majority of the wounds were gas gangrenous.

In a large proportion of these the other conditions were almost the same as in wounds received in quiet times. The same type of *high explosive* was employed, and many of the wounds were treated almost as expeditiously as in normal times, and yet they became gangrenous. This striking fact is illustrated also in other fronts at the present time, where the incidence of gas gangrene has much diminished since the earlier part of the war, although conditions of tissue injury, multiple infection, etc., remain the

same. The explanation may be in part due to a prompter and better mode of treatment of the wounds, but undoubtedly the most predominant fact is the difference in the physical condition of the men at the moment of receiving the wound. They are now more often relieved, and their physical welfare attended to much more efficiently.

Lastly, the fulminating type of gas gangrene which has been previously described with special reference to those wounded men whose bodies were seen swollen with gas almost to double their normal size within eight to twelve hours after the infliction of the wound, is a rare experience at the present time; and this fact seems to point also in the same direction, that the devitalising conditions of fatigue which then existed were highly important predisposing causes, not only of gas gangrene, but of the severest type of gas gangrene. It should always be remembered that gas gangrene cannot supervene in the living body unless there be a very greatly diminished tissue resistance. That is the *sine qua non* of gas gangrene in wounds, for the infection is present in nearly all cases. Conditions of severe fatigue and also, obviously, of shock and hæmorrhage, which notoriously weaken the vital reactions of the tissues, cannot fail, therefore, to be of immense importance in determining the incidence and severity of gas infection.

Exciting Causes of Gas Gangrene.—These are, of course, the anaerobic bacteria, whose source is fæcal material, and whose spores gain access to wounds in pieces of clothing and soil carried in by the missile. These have been dealt with in detail in the chapter on "The Bacteria of Wounds."

Pathology

On this important and interesting subject a new literature has sprung up in the past two or three years.

The earlier papers on this subject were by d'Este Emery and Kenneth Taylor, who took somewhat different views of the gangrenous process. These views were summarised later by Cuthbert Wallace* as follows:

D'Este Emery's View.—The toxin kills the leucocytes which are the natural protection of the body. To have a sufficient supply of these it is necessary that the circulation be intact. Therefore, tissue devitalised by trauma, by constriction of the limb, or by actual damage, will favour the disease. Why, however, does the disease not stop when healthy tissue is reached? The explanation lies in the fact that the toxin, when present in large amount, inhibits emigration and kills the leucocytes. If there is no free escape, the toxin accumulates to such an extent that it soaks through the healthy tissue and kills the defensive leucocytes, and so the gangrene spreads.

Taylor's View.—The mechanical action of the pressure produced by the gas is usually, if not always, the most important part of the infection. It brings about the death of the tissues from (*a*) the resulting anæmia,

* *British Medical Journal*, September 16, 1916.

(*b*) the actual mechanical fragmentation of the muscle substance, (*c*) the mechanical scattering of the infection. He shows in the earlier part of his paper that the experimental injection of the exo-toxin produces softening of muscle and parenchymatous degeneration of the liver cells. His experiments *in vitro* show the same effect on pieces of muscle. He suggests that the rapid systemic intoxication is produced by the breaking down of the muscle substance, as injection of the exo-toxin does not produce an effect comparable to that seen in the clinical course of the disease.

Cuthbert Wallace points out that these two theories differ mainly in the part played by the gas. Taylor thinks it plays the most important part in the spread of infection, while d'Este Emery lays most stress on the bacterial toxins. Taylor believes that the disease is mainly one of muscles; d'Este Emery thinks that this is a mistake, and that it is only the fact that there is so much gas produced from muscle sugar that leads to this assumption.

In commenting upon gas gangrene from his own experience, Cuthbert Wallace gives it as his impression that the disease is chiefly one of the muscles. The tendency of later writers, such as McNee and Dunn,* has been to regard the disease as essentially one of the muscles. The latter writers have made a careful and elaborate investigation into the method of spread of gas gangrene into living muscle, from which they conclude that the rapidity of spread is accounted for by the peculiar anatomical structure of the muscular tissue. The sheaths enclosing the long individual fibres are so easily detachable as to form potential spaces into which toxic material can readily pass, causing necrosis of the fibres.

It is obvious, therefore, that some confusion of thought exists as to the actual sequence of events in the spread of gas gangrene.

The present writers, in view of experience gained in the line, at the casualty clearing station, and the base hospital on two fronts, are not disposed to concur entirely with this later tendency to regard the disease as essentially one of the muscles. It is admitted that muscle is involved in by far the vast majority of cases of gas gangrene. The reason for this is, however, believed to be that in the vast majority of severe wounds with gross damage to tissue, muscle is one of the tissues most severely involved, and also that grossly injured muscle is a very favourable medium for the growth of sugar-splitting anaerobes. On the other hand, however, numerous cases have been met with in which the disease has been both confined to tissue other than muscle, and has been observed to spread in tissue other than muscle.

In proof of this point the authors can quote six types of wounds which they have observed:

1. **Hæmothorax Cases in which Localised Areas of Gas Gangrene occur in the Extravasated Blood-Clot.**—In penetrating chest wounds with

* *British Medical Journal*, June 2, 1917.

hæmothorax gas gangrene never occurs where there is free air entry into the open pleural space. But in a large number of these cases the pleuræ very rapidly shut off from the wound accumulations of extravasated blood. If *B. perfringens* or other anaerobe has chanced to lodge in these, it finds itself implanted in a most suitable culture medium under anaerobic conditions. *B. perfringens* is well known to have no power of growing in healthy fresh serum, but it grows vigorously in serum from the body after death and in serum which has been trypsinised, and occasionally also in the blood-stream during life, when that has been altered by the presence of another organism or by some devitalising condition. It is the same with blood which has been extravasated and bottled up in the tissues for some time. It is an inert dead mass and practically a foreign body. As such, it is a culture medium most suited to the tastes of *B. perfringens*. Hence in those closed-in accumulations of extravasated blood in the pleural cavity we often find circumscribed putrid areas of gas gangrene.

2. **Retroperitoneal Hæmatomata caused by Spent Pieces of Shell.**—Gas gangrene is well known to occur in these, and to spread round to the anterior abdominal wall, not in the abdominal muscles, but in the retroperitoneal areolar tissue.

It is true that here the muscle in the neighbourhood of the wound is also damaged, though usually not very grossly so. But in most of these cases no evidence of anaerobic activity is found in the muscles, and the gaseous œdema is confined to the cellular tissue. Here, again, in the blood-clot, deep down in the wound and far away from the atmospheric oxygen, a suitable anaerobic culture medium is formed for the causal organisms.

3. **Gas Gangrene of the Brain.**—A considerable number of these cases have been seen. Here it is the brain tissue which is affected by the gangrenous process. Gas gangrene practically never spreads in the membranes, for they quickly shut themselves off, and, in addition, like all serous membranes which are actively phagocytic, they have very great powers of resistance to anaerobes.

4. **Gas Gangrene in Wounds of Subcutaneous Tissue only, Muscle not being Involved.**—This was seen by one of us in the earlier days of the war again and again in the line. The case is recalled in particular of a regiment which took part in a famous battle in May, 1915. When these men went into the trenches to take the place of another unit they were hardly able to crawl and were, in fact, worn out with fatigue. Many of these men fell victims to machine-gun bullets. Some of them were seen eight hours after being hit, and they were then dead and the whole of their subcutaneous tissues blown up with gas. One such case in particular is recalled which was examined most carefully for wounds, and the only one discoverable was a superficial bullet wound of the thigh which had not penetrated the deep fascia. Such cases rarely occur now, and are

probably accounted for by the extremely fatigued condition of the men at the time of being hit.

5. **Gas Gangrene in the Subcutaneous Tissue following Surgical Emphysema.**—One remarkable case of this nature was seen by one of us. This was a penetrating wound of the chest with extensive surgical emphysema all over the trunk and genitals. Within forty-eight hours this emphysematous area became the seat of gas gangrene which spread rapidly throughout the subcutaneous tissue and brought about the fatal issue. It should be remembered in this connection that when the entry of the air into a surgical emphysema is stopped, the air becomes very rapidly absorbed, and it has been proved that the oxygen of this air is absorbed more quickly than the nitrogen. Thus within a day or so there would remain a large area of subcutaneous tissue with meshes filled with nitrogen. Such tissue, in so far as the separation of the planes is concerned, resembles the similar condition in recently wounded muscle, and in the latter *B. perfringens* luxuriates very commonly.

6. **Gas Gangrene spreading upwards in a Limb in the Areolar Tissue around the Vessels, in the Intermuscular Septa, and in the Subcutaneous Tissue.**—This is a matter of common experience in connection with wounds of the leg. If the muscle be damaged and gas gangrene occur, it commonly spreads upwards in the muscle sheath and between the fibres until it reaches the insertions of the muscle around the knee-joint. Its further upward spread takes place in the areolar tissue around the great vessels, whence it spreads into the subfascial areolar tissue planes of the thigh. In an amputation through the thigh performed for such spreading gangrene this areolar tissue can nearly always be seen to be greenish-yellow and œdematous or even gelatinous. In some cases the upward spread from the leg wound takes place in the subcutaneous connective tissue; whence the process spreads to that of the thigh. These are the cases in which the thigh becomes crepitant.

From what has been said it becomes evident that gas gangrene is a disease of any devitalised tissue. The only tissue which seems almost exempt from its action is that of serous membranes, the reason probably being that they are so actively phagocytic and that *B. perfringens* and other anaerobes very readily succumb to phagocytic action, especially to that of macrophages. Even serous membranes are, however, not in every case exempt, for we have seen very occasional cases of gas gangrene in the peritoneal cavity and in the knee-joint, and more commonly in the pleural cavity as already stated. At the same time, however, it is in the muscles that gas gangrene is found most frequently, and most typically present, the reasons probably being that muscle is so frequently damaged in war wounds, that the damage is of a special kind, and that the damaged muscle is an exceptionally favourable medium for *B. perfringens*, which is the most common primary causal organism. In many cases, as is well known, the infection is contained entirely within a single muscle or group of

muscles, and the disease can be arrested by ablation of such muscle or group.

What is the special nature of the damage done to muscle in a war wound ?

One of us had the opportunity while in the line of securing a number of specimens of wounded muscle within a few minutes of the infliction of the wound. These specimens included the part of the muscle actually penetrated by the missile, the varying lengths of the muscle above and below the wound which did not contract nor bleed, and a certain amount of healthy living muscle in the parts distal to the latter. The specimens were cut off with a sharp scalpel and immediately placed in 75 per cent. spirit. Subsequently the tissues were dehydrated, embedded, and cut. The sections showed the appearances illustrated in Plate II.

The striking abnormality presented by sections through the "muscle stupor" area was the presence of considerable spaces within the individual muscle fibres, and between them and the sheaths. In the neighbourhood of these spaces the fibrillæ had a crushed appearance. These spaces in the fibres and between fibre and sheath were shown by serial sections to extend for a varying distance of 1 inch or more, up and down the muscle on each side of the wound. In some cases these appearances extended in modified degree almost to origin and insertion of the muscle.

In another set of sections of muscle removed about two hours after the infliction of the wound, when the muscle was in the state of "acute muscle œdema," the following appearances were presented: The spaces between fibre and sheath were larger than those of the first set, and extended a great part of the way or the whole way around the fibre, so that the fibre was partially or wholly cut off from its blood-supply in the sheath. In some sections spaces were also seen within the fibres themselves. It was presumed that these spaces had been filled with extravasated lymph. At the time when the sections were taken there were no appearances of the onset of infection.

McNee and Dunn* have shown that in a muscle in which spreading gas gangrene is occurring the following appearances are presented in the part distal to that which is actually gangrenous :

1. Many of the fibres are completely separated from their sheaths by considerable spaces.
2. Those fibres which are so cut off from their blood-supply show coagulation necrosis.
3. The other fibres in the section show paler staining reaction and partial loss of striation.
4. These appearances gradually tail off as normal muscle is reached.

We have been led to believe from such histological work and from our clinical experience that the sequence of events when a wounded muscle

* *British Medical Journal*, June 2, 1917.

becomes invaded by gas gangrene is usually represented in the following stages :

1. Disruption.
2. Lymph exudation.
3. Infection.
4. Gas and toxin formation.
5. Extension.

1. **Disruption.**—The mechanical effect of the missile is to drive a volume of compressed air into the muscle substance. This air, following the path of least resistance, is simultaneously forced up and down the muscle substance between and within the individual fibres, separating them from their sheaths. Air-spaces are thus produced between and within the fibres for a varying distance in the muscle on each side of the penetrated part. At the same time the vitality of the fibres themselves is impaired by the mechanical violence and by the anæmia produced by pressure of the air and the interruption of the blood-supply.

2. **Lymph Exudation.**—Within a short time reactionary œdema occurs; the spaces become filled with lymph and the muscle swells; the lymph coagulates; the muscle herniates out of the wound owing to increased pressure, and access of air to deeper parts of the wound may be cut off. The fibres are devitalised from pressure and consequent diminution of their blood-supply.

3. **Infection.**—The anaerobes introduced into the depths of the wound along with the missile find in the devitalised muscle fibres, the coagulated lymph in the muscle spaces, and the absence of oxygen, congenial conditions for their growth and development.

4. **Gas and Toxin Formation.**—The saccharolytic group, especially *B. perfringens*, are the first to act vigorously. They ferment the muscle sugar, forming acids and non-odorous gases, and cause the muscle to die and its colour to change to brick red. A proteolytic action next takes place, and this is caused in part also by *B. perfringens*, but chiefly by the proteolytic group of anaerobes of which *B. sporogenes* is the commonest. The result of the protein lysis is the liquefaction of the lymph and putrefaction of the muscle fibre. The liquefaction of the lymph may be partly due to aerobic organisms. From the muscle proteins are formed amino-acids, ammonia bodies, and malodorous gases, mostly compounds of sulphur; and the affected muscle at this stage becomes blackened by the interaction of the iron (from hæmoglobin) and the sulphur. The typical and profound toxæmia of gas gangrene now occurs, the chief agents probably being, as Dale has shown, the extremely toxic ammonia bodies formed from disintegrated protein. To a certain extent, also, the milder true bacterial exotoxins exert their poisonous action on muscle and liver cells.

5. **Extension.**—Gas formation, which commenced early in the stage of infection, steadily increases, and exerts an increasing pressure. This

PLATE II.

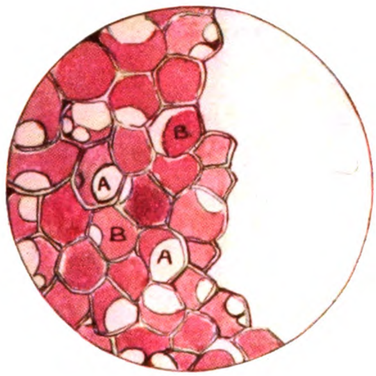


Fig. 1.

Fig. 2.

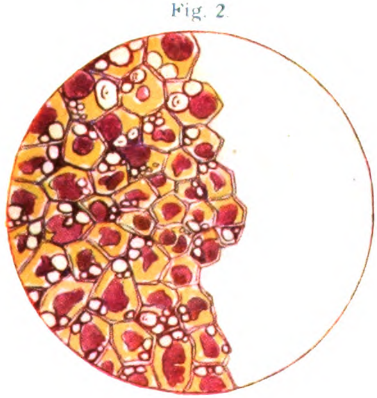


Fig. 3.

Figure 1. Disruption
" 2. Oedema
" 3 Gas Formation

To face page 156.

pressure enables the gas to pass further up into the normal muscle, together with the liquefied lymph, stripping the muscle fibres from their sheaths and causing their devitalisation by pressure and consequent anæmia. The diffusible toxins from the actively gangrenous area rapidly pass up in the lymph-stream and in the liquefied extravasated lymph within the fibre sheaths, causing necrosis of the stripped and devitalised fibres. *B. perfringens* and later other anaerobes rapidly follow in the same paths, and ferment and digest the necrosed fibres. A vicious circle is produced, and more and more tissue becomes gangrenous and more and more toxin is produced as the process extends. The advance of the process is so rapid that a leucocytic reaction cannot develop in time to check it. Hence in

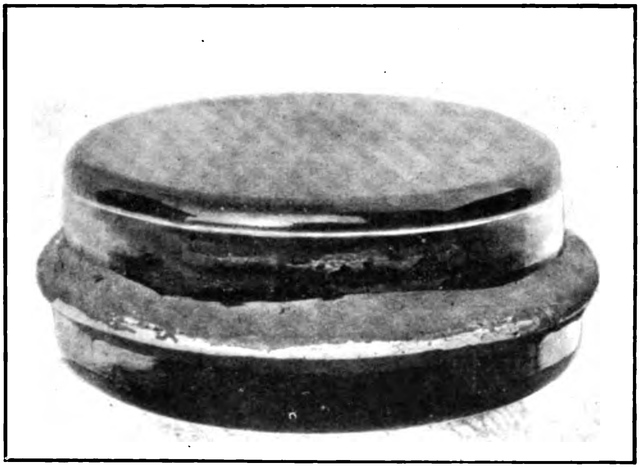


FIG. 36.—Method of culture of *B. perfringens.*

Two Petri dishes are sealed together by means of putty. A perforated tin diaphragm is interposed between them. In the lower dish is placed a solution of pyrogallate of potash, in the upper dish is the medium for the growth of the bacillus.

rapidly spreading gas gangrene the bacilli are always found in advance of the leucocytes.

When the end of a muscle is reached, the toxin-containing fluid may be forced into the areolar tissue around the vessels, and by this route spread into the remoter parts. Ablation of the infected muscle before the infection has passed beyond it may stop the process. The process may also be arrested by free incisions through the advancing infected fluid in the muscle sheaths, whereby the anaerobes are rendered less able to attack the devitalised fibres. If in any way the rapidity of the process is arrested, a leucocytic reaction is able to develop, the bacilli are phagocyted, and the gangrene becomes localised.

During the saccharolytic period of muscle invasion, the colour of the muscle is brick-red, and its consistence friable and spongy and not unlike congested lung tissue. This is the stage of "red death." When the pro-

teolytic period begins the colour changes to an olive-green, and thence to a glistening black, and the odours at the commencement of this state are very foul. This is the "black death" stage. As gas accumulates the skin becomes tense, dirty white, then mottled with purplish areas, and finally blebbed, the blebs containing fluid stained with altered blood.

In tissues of the body other than muscle the initiation and spread of gas gangrene is exactly similar, except that it is a much slower process and more liable to become arrested and localised at any stage. Extravasated blood, brain, and areolar tissue are less readily fermentable substances than is muscle, and less suitable as pabulum for anaerobes. In addition, the spaces in their substances into which toxic fluid can pass are much less easily formed than in the case of muscle, where fibres separate readily from sheath. In some cases, however, such as in gas gangrene superimposed on a surgical emphysema, where the tissue spaces are already opened up, the spread may be very rapid. In case of severe fatigue the vital resistance is much diminished and the rate of spread correspondingly increased.

The final stage of gas gangrene is successful invasion of the blood-stream by the bacilli. This occurs when the blood is sufficiently altered to permit of it. In most cases the change is not brought about until just before death, but in occasional cases the bacilli enter the blood-stream at a comparatively early stage, and cause pyæmia or "metastatic gas gangrene." Such a condition is almost invariably fatal, although a few recoveries have been reported.

Symptoms of Gas Gangrene.

Symptoms will depend upon whether the condition is early or late. Early gas infection may give rise to no symptoms at all beyond pain. A very large proportion of war wounds contain the gas-gangrene bacillus. In many of these the infection never becomes established; in others it is arrested at a very early stage and the symptoms are minimal. Gas gangrene gives rise to definite symptoms only when it has firmly established itself.

Intermediate Stage.—In what may be called the intermediate stage there is much pain, owing to swelling, and the affected part is usually resonant to percussion. At this stage constitutional symptoms due to toxæmia are present. The lips present a peculiar cyanotic colour which is typical of the condition; the patient looks ill, the pulse is rapid, and the temperature varies between 102° and 103° F.

Gangrenous Stage.—In the final or gangrenous stage the skin assumes all hues from a brick-red to a blackish-green. Blebs appear containing both fluid and gas, the typical smell of gas gangrene is present, and the whole part is now painless and dead. Constitutional symptoms, the result of toxæmia, at this stage are most pronounced. The patient is ashen about the face, cyanotic about the lips, the skin is cold and clammy, the tempera-

ture is often subnormal, the pulse running and weak, and often there is coffee-ground vomiting.

The prognosis in the latter stage is exceedingly grave, and many of these patients die unless rapid and energetic measures be taken.

Diagnosis

The whole secret of success in treatment lies in an early diagnosis. The first important observation to be made is whether or not a swollen condition of the tissues is present in the neighbourhood of the wound. Secondly, is the foreign body still in the tissues or has it emerged ?

If there be swelling of the wounded part, and if the wound of entry be caused by a small missile, the swelling may be due to one of the three following causes :

(1) Hæmorrhage into the tissues, the result of a wounded vessel.
(2) Œdema of the tissues due to trauma.
(3) Gas-formation.

Fig. 37.—Penetrating wound of the thigh.
The skiagram shows the foreign body and the presence of gas in the tissues.

In the case of hæmorrhage the limb is uniformly swollen, and firm to the hand. The pulse in the vessels below may be good, and on gently compressing the limb blood-clot can often be expressed from the wound of entry. The swelling is dull to percussion, and pain, though present, is not acute. Finally, the situation of the wound may give some indica-

tion as to the possible source of the hæmorrhage, and an X-ray will confirm the presence or absence of gas in the tissues.

If the swelling be due to traumatic œdema, there is acute pain on palpation, with herniation of muscle from the wound, and the part is non-resonant. As a rule, at this stage there are no constitutional symptoms.

If the swelling be due to gas-formation, the part is tender to the touch, it is resonant to percussion, and constitutional symptoms are present.

If the foreign body be still in the tissues, and if there be no obvious swelling of the part, though pain be present, an X-ray will reveal not only the position of the foreign body, but also the presence of gas. If doubt exist about the gas shadows shown on the plate, another X-ray taken an hour later will determine whether the shadows have altered in size. If this be the case, it may be concluded that gas-formation is progressing.

The general condition and appearance of the patient are valuable guides, for there is a characteristic facies already referred to, associated with gas-gangrene toxæmia.

In the advanced stage, when the skin is discoloured and blebbed, the diagnosis is obvious.

Complications of Gas Gangrene

These are—

(1) Local spread of the condition.
(2) Gas-gangrene septicæmia.
(3) Gas-gangrene pyæmia.

The rate of spread of gas gangrene in the tissues varies. In some instances it is slowly progressive. A wound may have been satisfactorily excised, leaving a resulting wound surface which to the naked eye appeared both clean and healthy. Within the next few hours the tissues adjacent to and at some distance from the wound itself are found to be the seat of a spreading gas gangrene.

On the other hand, the rate of spread may be much more rapid, as is shown by the following example :

Lieut. —— was wounded on August 4, 1916, in France. He arrived at a casualty clearing station twelve hours later with a large, dirty wound of his right leg involving a compound comminuted fracture of the tibia. The wound was excised piecemeal, and a suitable dressing applied (in this case a salt pack owing to hæmorrhage). Five hours later he was cyanotic about the lips, was an ashen colour, and was vomiting. An examination revealed a spreading gas phlegmon which had reached halfway up the thigh. A rapid guillotine amputation through apparently sound tissue was performed, and both arrest of the gas-infection and recovery of the patient followed.

Gas gangrene may be lighted up in a wound which has settled down and

appears to be undergoing a satisfactory and uncomplicated course of sterilisation. The following case illustrates a not uncommon occurrence :

Pte. —— was wounded on May 8, 1917, in the Balkans. He sustained a compound comminuted fracture of the right humerus in its upper third which involved the shoulder-joint, and a severe compound comminuted fracture of the right femur in its lower third involving the knee-joint. The comminution in the case of the femur had contused the popliteal vessels. All went well until the tenth day after the injury, both temperature and pulse being normal. Suddenly and without warning a severe secondary hæmorrhage occurred from the damaged popliteal vessels. An amputation was performed through apparently healthy tissue, yet within two hours of the amputation (the stump being left open) a fulminating gas gangrene starting from the stump and spreading up the thigh to the abdominal wall occurred, and death followed in a few hours.

Gas-Gangrene Septicæmia.—*B. perfringens* septicæmia, though comparatively rare, has nevertheless occurred in a number of cases.

It would appear that a severe toxæmia, the result of gas gangrene, is a far more rapidly fatal condition than that of a true gas-gangrene septicæmia. In the former case, cyanosis of the lips, an ashen appearance of the facies, a cold clammy skin, with a rapid, weak pulse, subnormal temperature, and biliary vomiting, constitute the typical picture. In strong contrast are the symptoms of gas-gangrene septicæmia, for here the patient has usually a good colour, the tongue is clean and moist, the appetite is good, the evening temperature reaches 102° to 103° F., coming down to normal or

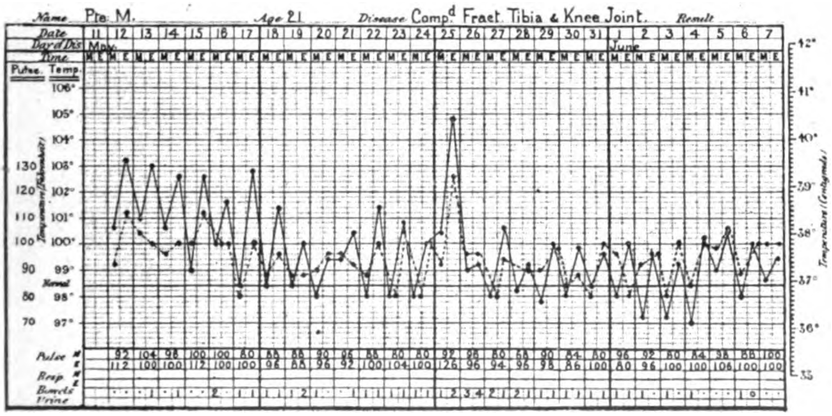


FIG. 38.—*B. perfringens* septicæmia.

below normal each morning. This type of septicæmia may continue for days or weeks, the patient still keeping up, until finally the blood infection becomes complicated by the presence of other organisms, either streptococci, staphylococci, or even *B. coli*. At this stage the patient steadily takes

a downhill course ; he goes to skin and bone, bedsores supervene, and he dies. We have, however, seen a few cases of uncomplicated gas-gangrene septicæmia recover.

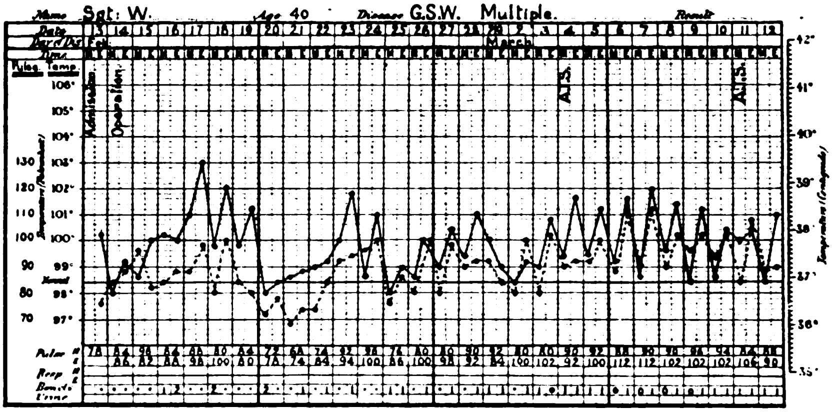


FIG. 39.—*B. perfringens* septicæmia.

Gas-Gangrene Pyæmia.—This rare condition is usually a complication of wounds in which bones, chiefly of the lower extremity, are involved. The appearance of these metastases is most extraordinarily rapid and unexpected, and when once established the condition is extremely fatal and death rapidly follows.

One or two examples will best illustrate this complication.

Pte. —— fell off the back of a lorry, sustaining a severe compound fracture of the left tibia and fibula in the lower third. He was admitted to hospital, where the wound was immediately attended to under an anæsthetic. On the following day, despite the regular hourly instillation of the hypochlorites, his leg had become gangrenous up to the knee. Amputation was performed through the lower third of the thigh, the flaps stitched open, and regular hourly instillation of antiseptic into the stump was carried out. The same evening he was rational, taking food, and reading a magazine. He complained, however, while one of us was in the ward, of some stiffness over his left scapula. An examination at 8 p.m. revealed nothing. At 3 a.m. there was a large area over the posterior triangle of the neck which was crepitant and had commenced to become discoloured. At 4 a.m. he was dead. An early post-mortem examination revealed gas in all the organs of the body, and a histological examination of the liver and heart muscle revealed a condition of acute autolysis. A bacteriological examination of the heart's blood very soon after death showed *B. perfringens* to be present in pure culture.

Pte. —— sustained a gunshot wound of the left thigh involving only soft structures. The wound was lacerated, but appeared to be clean and sterilising satisfactorily. On the second night after admission—that is,

the third day after injury—he complained of pain in the right buttock, and an examination revealed a brick-red blebbed and crepitant condition of the skin and subcutaneous tissues. He had commenced to vomit, and presented all the symptoms of an acute gas-gangrene toxæmia. He died two hours later.

The post-mortem findings were identical with those of the preceding case. We have witnessed two cases where gas-gangrene metastasis has occurred in the lung. One of these cases, which was associated with a severe compound fracture of the femur, recovered ; the other case, associated with a wound of the opposite lung, died. The latter case is especially interesting in that there was a second infarct in the penis. The result was at first an acute, painful state of priapism. Later the penis became crepitant, very discoloured, he could not pass water, and a catheter passed only with difficulty. Free incisions were made into the organ, which, however, did not arrest the gangrene. He lingered for ten days before death.

In both these cases of lung metastasis the breath was very foul and pungent, the odour resembling that of true gangrene of the lung.

Treatment of Gas Gangrene

It would seem that surgical measures alone are in a number of cases insufficient to arrest the progress and spread of this condition. There is evidently something more than the exciting cause to be dealt with, and the more we see of the condition, the more we realise this important fact.

After a wide experience of wounds, extending over three years, we are day by day coming to the conclusion that the general condition of the soldier at the time he is wounded is of paramount importance in determining the onset or severity of gas gangrene. Surgical attention to the wounds and the parts around it must form the mainstay of treatment when the condition is well established, but it should ever be remembered that this is in a broad sense only a fraction of the treatment.

The treatment of gas gangrene will comprise:—

(1) Treatment in the line and at the forward units.
(2) Treatment at the casualty clearing station.
(3) Treatment at the base hospital.

Treatment in the Line and at the Forward Units.—Treatment here is mainly prophylactic, and aims at improving the general condition and helping the natural powers of resistance. All wounded men should, if possible, be made thoroughly warm, given hot and nourishing drinks, with stimulants if shock be present; hæmorrhage should be immediately arrested, and any fracture should be securely immobilised prior to transport. At the advanced dressing station further hot drinks should be administered, and food if the patient can take it. A short sleep, if conditions permit, is most desirable before transport to the field ambulance.

If available, large quantities of sodium bicarbonate should be given by mouth.

At the field ambulance the wounded part should be inspected and the dressing removed. The wound should be filled with hypochlorite solution, and a gauze dressing soaked in this antiseptic should be laid over it. Over this a piece of jaconet should be placed, and wool with a *loosely applied bandage* completes the dressing. Hot stimulating drinks should be given at this unit, and a sleep allowed if conditions permit. Glucose and sodium bicarbonate should be administered by mouth if the patient can take it.

It may happen, however, that in some situations it is impossible to get a wounded man out of the line immediately, and he has to stay for some hours at the regimental aid-post. In this case the first field dressing must be removed, and the wound filled with Dakin's solution or eusol and a loose dressing applied. The limb must be carefully watched for any swelling. Should gas gangrene supervene—and we have seen this occur within two hours of being wounded—and should the condition be spreading, then amputation is the only hope.

Men arriving at the field ambulance with limbs gangrenous and dead should undergo amputation at once. They should not be sent on to the casualty clearing station in this condition, unless it is absolutely necessary. During the operation normal saline solution should be administered intravenously or subcutaneously, and with it three or four teaspoonfuls of sodium bicarbonate to the pint. This latter drug has often done good in bad cases. It is highly probable that its beneficial action is due to the neutralisation of the acid products of fatigue present in the tissues at this stage.

Should gas gangrene be established in a wound by the time the field ambulance is reached, and should it be slowly spreading, then excision of the wound, with free incisions into adjacent tissues and the application of a Carrel-Dakin dressing, should be practised. Field ambulances, as we knew them in France, had not only the accommodation and equipment necessary for doing this work, but they had many competent surgeons willing and eager to carry it out. From what we saw at the casualty clearing station, surgical work performed at the field ambulances was always good and sound, and patients who had been fortunate enough to receive early treatment at these units invariably did well.

Treatment at the Casualty Clearing Station.—Treatment is both local and general, and depends upon the degree of gas infection present in the wound and neighbouring tissues. The four chief types of gas infection seen at these latter units are—

(1) A gas infection localised and confined to the wound.
(2) A slowly spreading type.
(3) Cases in which single muscles or groups of muscles have been picked out.
(4) A fulminating type.

(1) *Gas Infection Localised and Confined to the Wound.*—This condition is always an indication that the wounded man is holding his own against the infection. Hence at this stage nothing must be done which may in any way jeopardise his chances by diminishing his resisting powers.

A rapid excision of the wound should be performed under ether anæsthesia, normal saline with bicarbonate being slowly administered intravenously during the operation. The wound, now excised, should be immediately submitted to a process of continuous sterilisation by the Carrel-Dakin method, and the patient returned to bed and made warm. Let it be repeated that the *operation should be carried out with all possible speed*, for a long operation is at this stage most harmful, and may easily turn the scale in the wrong direction.

(2) *The Slowly Spreading Type of Gas Gangrene.*—Excision of the wound must be carried out with all possible speed in this class of case. This completed, free incisions must be made into the neighbouring tissues, down to and including the deep fascia, and extending well beyond the limits of spread of the infection.

Continuous sterilisation is now started at once by the Carrel-Dakin method, and the patient is sent on to the base hospital as soon as possible.

(3) *Cases in which a Solitary Muscle or Groups of Muscles have been Singled Out.*—Treatment here is complete excision of the affected muscle or groups of muscles. It is useless to try and remove part only of an infected muscle, as the process will certainly recur in that part that has been left behind. After excision has been performed, a Carrel-Dakin dressing is applied, and the patient evacuated as soon as possible to the base.

(4) *The Fulminating Type.*—Here the rate of spread of infection is so rapid that within a few hours not only may a whole limb be dead and putrid, but the process may have encroached for some considerable distance on to the trunk. Immediate amputation by the most rapid means possible is the only treatment; and although the diseased condition of a limb may have extended so far that healthy flaps cannot be fashioned, the surgeon should not hesitate to perform amputation, even if he have to do it through unsound or even gangrenous tissue.

In cases where the disease has extended from the limb to the trunk, high amputation should still be carried out, and free incisions made into the diseased tissues of the stump and trunk, such incisions extending well beyond the limits of the disease. These amputation stumps are usually of the guillotine or flush variety, and both to them and the diseased incised tissues above them a Carrel-Dakin dressing is applied, and an energetic continuous sterilisation started with as little delay as possible.

If the gangrenous process has reached a level below the knee, amputation can be carried out in the lower third of the thigh. We have latterly employed the method of equal long anterior and posterior skin flaps, with a guillotine division of the muscles at a higher level, and a division of the bone still higher up. Should the flaps contain much disease, they are

stitched back, and the open stump is submitted to continuous sterilisation by the Carrel-Dakin process. If, on the other hand, the flaps appear to be sound, they are brought together with five or six sutures and Carrel's tubes are included in the stump. Hourly instillation of the antiseptic into the stump is carried out, and in a large percentage of cases the stump has healed without any trouble.

A number of cases arrive at the casualty clearing stations in a desperate condition of toxæmia. The main point that the surgeon should aim at is to cut off the supply of toxin to the individual, and this can only be done by removing the diseased part. Even though he can remove only part of the diseased tissues by amputation through gangrenous material, he is nevertheless diminishing the dose of toxin the patient is receiving. We have now performed very many amputations through gangrenous tissue, and in a considerable number of these the disease had spread to the trunk. Results quite justified the procedure, and out of a special series of fifty cases treated at a base hospital there were twelve deaths and thirty-eight recoveries. Out of the fifty cases, gangrene had reached the trunk in six, and out of the six three recovered. In every case amputation was performed through gangrenous tissue. This, then, gives a recovery of 76 per cent. All the thirty-eight cases were kept until the stumps had healed, and all were submitted to secondary suture.

It would appear that when once as large a part as possible of the disease is removed from the individual, with the proportionate reduction in the amount of toxin absorbed, then with the aid of active antiseptic measures the patient's resistance is often sufficient to overcome the remaining infection.

It must be remembered that amputation in these desperate cases has to be carried out very rapidly, and the quickest method is the flush amputation. Should the leg be involved and the condition of the patient critical, flush amputation through the knee-joint is the quickest and safest method, taking care to remove the patella. There are no hard-and-fast rules to be laid down in the methods of performing these amputations, for each case must be treated by whatever method is quickest and best. A flush amputation should not take longer than five to seven minutes from start to finish, and we have now done a considerable number in this time under gas anæsthesia. There is little shock—in fact, far less shock than is occasioned by the use of other general anæsthetics—and the poisonous effect of such general anæsthetics on the internal organs of excretion, already overloaded with toxins, is thereby avoided.

During the operation saline solution with sodium bicarbonate and brandy should be run into the subcutaneous tissues of the axilla. Two pints of saline and bicarbonate with one ounce of brandy has been the amount we have always employed.

On return to bed, hot-water bottles are applied, and the patient soon breaks into a sweat. Calomel (gr. v.) should be given at once, followed

by a dose of salts and an enema, if necessary. Hot stimulating drinks and easily digestible food are given, and glucose in doses of 1 drachm three times a day seems to do good in these cases. We have administered glucose both by mouth and rectum very frequently to these cases, and certainly it seems to have an effect which is both immediate and lasting, and we can strongly recommend it.

When the trunk is involved, the disease usually occurs in the abdominal wall as a complication of gunshot injuries of the back which have given rise to abdominal symptoms, necessitating laparotomy. Free incision is the only treatment. We treated a few of these cases—for we have not seen many—with salt packs, but when once the condition is established in the anterior abdominal wall, the disease has almost always proved fatal. We saw only two recoveries, and these were both of a limited type.

ANTI-GANGRENE VACCINE.—We have given this vaccine a fair trial, both in early and late cases, but in not a single case can we say that it influenced the course of the disease. Perhaps its use as a prophylactic may be of some good, but of this we can say nothing definite, as it was not widely used in this connection.

Treatment at the Base Hospital.—Men arriving with gas gangrene at the base hospital are those who have not received treatment at the casualty clearing stations either through rush of work or on account of the apparently insignificant nature of their wounds. Small wounds of soft parts in which the missile with its piece of clothing are still present, and which when leaving the casualty clearing station appeared harmless, have by the time the base hospital is reached lighted up into an acute spreading gas gangrene. This we have seen times out of number, and although no blame whatever can be attached to the clearing stations, to whose surgeons, from experience, our sympathies go forth, it shows the importance of the universal early removal of foreign bodies and the excision of an infected wound.

The treatment of gas gangrene at the base hospital does not differ at all from that recommended at the casualty clearing station. The main point is an energetic and thorough sterilisation of all gangrenous wounds, after excision, by the Carrel-Dakin method. The more we have persevered with this method of treatment, the more excellent have been the results.

Amputation stumps as they reach the base hospital are often crude, but to those with experience of the work of a busy casualty clearing station this is quite understood. At the latter unit these operations are mainly life-saving in nature for men whose condition is desperate ; hence the same surgical finish must not be looked for as could be obtained when the wounded man's general condition allows of a longer anæsthesia.

Treatment of the Complications of Gas Gangrene

Local Spread of the Condition.—Despite thorough excision of the wound, the condition in debilitated men may spread, although since the adoption of the Carrel-Dakin scheme this is far more rare than formerly.

Free incisions into the diseased tissues should be immediately carried out, and at the same time a barrage of some suitable antiseptic can be put up in the sound tissues beyond the area of spread.

Hydrogen peroxide, oxygen, or a full-strength solution of potassium permanganate, have been injected into the apparently sound tissues of a limb above and below the areas of spread. These antiseptics have been introduced both into the subcutaneous and deep tissues, and have been made to completely surround the limb.

Prior to the Carrel-Dakin treatment, when this complication was not infrequent, potassium permanganate seemed in a few cases to do good, but we never saw any benefit follow the use of oxygen or hydrogen peroxide.

Acute Gas-Gangrene Toxæmia.—In severe gas-gangrene toxæmia, where cyanosis of the lips, an ashen appearance of the face, a cold clammy skin, with uncontrollable vomiting, are present, the outlook is extremely grave. The local condition should receive attention on the lines already laid down. The stomach should be washed out with bicarbonate of soda (a drachm to the pint), an enema should be given to induce the bowels to act, and intravenous saline with bicarbonate should be administered.

Fraser and Bates recommend the use of intravenous eusol. We have repeatedly tried this, but have seen no good result from its use.

Nourishing liquid diet should be given if the patient can take it, and glucose has in many instances been of value.

Gas-Gangrene Septicæmia and Pyæmia.—It seems that no treatment benefits this fatal complication. In some cases of septicæmia of a subacute type the patient lingers on for three to six weeks before death. In these latter cases the tongue is clean, the colour is good, and the patients eat well. Later they gradually waste, develop bedsores, and finally die.

Out of five cases of gas-gangrene pyæmia, all died within forty-eight hours of the appearance of the metastases. No treatment seems of any avail.

CHAPTER VIII

GENERAL COMPLICATIONS OF WOUNDS *(Continued)*

Tetanus.

TETANUS was not an infrequent complication of wounds during the earlier weeks of the war, and during the battles of the Marne and the Aisne many wounded men contracted it.

To-day, thanks to the universal use of the antitetanic serum, coupled with a more thorough and up-to-date treatment of wounds, it is a very rare event. This very fatal disease is due to infection of a wound through contamination with dirt or clothing.

The specific organism is the tetanus bacillus. This bacillus is a sporogenous, Gram-positive anaerobe, the spore being terminal, giving it the appearance of a drumstick. It grows characteristically in stab cultures of gelatine, and in its sporogenous form it is very difficult to kill. Being a normal inhabitant of the soil, it is an ever-present danger to both men and horses who have been wounded, though horses will contract the disease from such causes as a picked-up nail. The size or extent of the wound is no criterion, for cases have occurred through the infection of trivial scratches caused by barbed wire, sores rubbed on the foot by a badly fitting boot, blebs that have broken on the foot, the result of frost-bite, and the like.

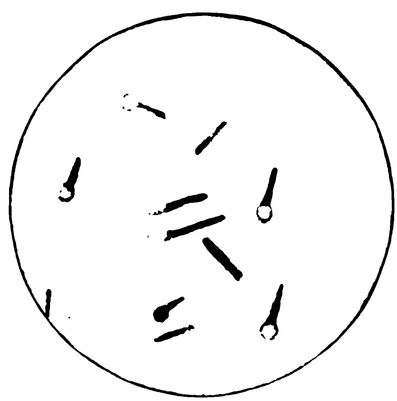


FIG. 40.—*Bacillus tetani.* (× 1,500.)

When once the bacillus has established itself in a wound, it is very difficult to isolate, being but one of a mixed infection. It is fairly agreed by most authorities that the bacillus does not migrate from the wound or its immediate surroundings into the tissues, but makes the wound a depot for elaborating its toxin. The toxin travels up the peripheral nerve trunks within the nerve sheaths and reaches the anterior horn cells, where some combination (probably of a chemical kind) takes place between it and the cell protoplasm. When the spinal cord is reached, some of the toxin gets

disseminated amongst the cerebro-spinal fluid. By this means motor cells are attacked other than those corresponding to the nerve trunks along which the toxin originally travelled from the wound.

The interval of time elapsing between the infliction of the wound and the onset of symptoms varies from five days to weeks. The commonest period is about eight days.

Symptoms.—The symptoms are local and general.

Local Symptoms.—Small wounds which are the site of tetanus infection rapidly assume an indolent nature. The wound becomes dry and covered with an unhealthy-looking greyish membrane, and there is little or no wound exudate. These wounds respond slowly, if at all, to treatment of any kind. On the other hand, large wounds may appear perfectly healthy and doing well when tetanus sets in. The earlier wounds of the war, however, which were complicated by tetanus were both highly infected and offensive.

The earliest local symptom is spasm or stiffness in the muscles *in the neighbourhood of the wound.* The stiffness or cramp complained of by the patient may be either continuous or intermittent. By comparing the injured side with the sound side, this stiffness or rigidity is readily felt. Such an early symptom should immediately arouse the suspicion of the nurse or sister who is looking after the case, and they should be urged to be ever watchful for, and without delay report upon, the slightest suggestion of anything of this sort, should it occur.

In other cases the first symptom observed is *trismus* or spasm of the masseters, preventing the patient from opening his mouth. There may be a feeling of stiffness in the muscles of the back of the neck. Any feelings of cramp in the jaw, neck, or limbs should be carefully watched for and reported by the sister in charge of the case.

Often accompanying trismus is the *risus sardonicus*, due to spasm of the risorius muscles.

Yet another early symptom is *difficulty in swallowing*, usually complained of by the patient, who will also say that his throat feels stiff.

General Symptoms.—General symptoms may either follow immediately upon or be delayed for three or four days after the appearance of the local symptoms.

They consist in general spasms of the muscles of the trunk, especially those of the back. They are exceedingly painful, causing the patient to cry out. With these spasms the body is distorted, opisthotonos, pleuristhotonos, or emprosthotonos resulting, the commonest being opisthotonos.

With these intermittent spasms, which as the disease progresses become more frequent, the patient rapidly wastes, becomes exhausted, and finally dies, conscious to the last.

Delayed Tetanus.—Tetanus has occurred in men some weeks after the reception of their wounds. This phenomenon, though not common, has occurred with sufficient frequency to demand attention. It would

seem that tetanus, like other infections, can lie latent in the tissues of an open or healed wound for some considerable period. An injury or further operation has been sufficient to bring about its recrudescence, in just the same way that we have seen sepsis lighted up in an old healed second-intention scar when a second operation has of necessity been undertaken in its immediate vicinity.

Again, later operations for the removal of foreign bodies from tissues that have healed have in a number of instances been sufficient to give rise to tetanus.

Here it is possible that the foreign body has become completely encapsulated with fibrous tissue, and though tetanus organisms be associated with it, yet they are harmless so long as the fibrous envelope is not destroyed.

Diagnosis.—This is not always easy. Early tetanus can be simulated by—

(1) Diseased conditions of the teeth.
(2) Malaria of the cerebral type.
(3) Septicæmia resulting from wounds.

FIG. 41.—Trismus associated with an impacted wisdom tooth.

DISEASED CONDITIONS OF THE TEETH.—On this front we have now seen a number of cases of trismus due to an impacted wisdom tooth. A careful

examination of the teeth should be undertaken, if necessary under an anæsthetic, and if an impacted wisdom tooth be present it should be removed. Trismus associated with an impacted wisdom tooth is always associated with pain in the tooth; there is no stiffness in the muscles of the back of the neck, and no feeling of stiffness in the masseter muscles.

Malaria of the Cerebral Type.—Cerebral malaria complicating wounds may closely simulate early tetanus. There may be difficulty in swallowing, stiffness of the muscles at the back of the neck, while the wound has assumed an indolent character not unlike a tetanus-infected wound. The patient may even have a spasm, though this spasm does not resemble true tetanus. We have seen cases where the flexors of the fore-arm and hand have been strongly contracted, the patient assuming the so-called "pugilistic attitude."

As a rule cases of cerebral malaria can be differentiated from tetanus, although on one or two occasions we have for hours been in doubt. In cerebral malaria there are mental symptoms or drowsiness, and the patient does not complain of any pain, cramps, or feelings of stiffness. A history of previous attacks of malaria, an examination of the spleen, and finally a blood-film, will all help to clear the diagnosis, while an intravenous administration of quinine will often finally settle the question.

Septicæmia resulting from Wounds.—Fortunately, since the general adoption of the Carrel-Dakin system of wound treatment, septicæmia has been a rare complication of wounds. There have been, however, a few cases, chiefly of the streptococcal variety, and the symptoms have on more than one occasion closely simulated tetanus.

Convulsions, spasms of groups of muscles, slight arching of the back, and a characteristic tremor, have all been present.

These spasms differ from true tetanus in that they are painless. At the same time, these patients have been semi-delirious. Wasting, and the rapid formation of bedsores have been present, but trismus has never appeared. Streptococci have on every occasion been isolated from the blood. A careful examination of the flora of these wounds has never revealed the presence of the tetanus bacillus.

The temperature has been that of a typical streptococcal septicæmia, and in those cases which died the post-mortem examination, both clinically and bacteriologically, proved septicæmia to be the cause of death.

Treatment of Tetanus—Prophylactic.—In tetanus, above all other diseases, the surgeon should remember that prevention is better than cure. Earlier in the campaign this complication was of frequent occurrence. To-day this is just the reverse, and we may safely rest assured that if every care be exercised in the carrying out of prophylactic measures, then one of the most dreaded and fatal complications of wounds has been overcome.

Prophylactic treatment comprises—

(1) Thorough surgical excision of the wound as soon after injury as possible.

(2) Application to the excised wound of an efficient antiseptic, preferably by the method of Carrel and Dakin.

(3) Administration of antitetanic serum to all classes of wounds, however large or trivial.

The first two of the above mentioned are described in the chapter dealing with the general treatment of wounds.

Administration of Antitetanic Serum.—This should be carried out at the earliest possible moment after the infliction of a wound. Five hundred units are given beneath the skin of the abdominal wall, between the shoulders, or beneath the skin of the anterior chest wall. The skin at the site of administration should be cleaned with spirit and then painted with iodine prior to giving the serum, which should be administered with a serum syringe that has been previously sterilised.

This part of the treatment is carried out at the field ambulances, and is carefully recorded on the soldier's field card.

All cases, however trivial, such as scratches from barbed wire, cuts contracted while opening tins, skin abrasions, and the like, should be immediately sent from the line to the field ambulance for a prophylactic dose.

All cases of frost-bite or trench feet in which the skin is broken should receive prophylactic treatment.

It has been found that in large, dirty wounds, such as those complicating bone, one dose of 500 units is insufficient, as cases of tetanus have occurred some days later while the wound is still dirty. In the instance of large, dirty wounds the dose of 500 units must be repeated weekly until the wound is clean and healthy.

From a good many thousands of cases where the dose has been repeated we have never seen any anaphylactic symptoms result.

Whenever a second operation is necessary, such as is required for secondary suture of a wound, or the subsequent removal of a foreign body after the wound has healed, a prophylactic dose of 500 units should be given subcutaneously at the operation.

Complications attending the Administration of Antitetanic Serum.—The only complication is serum disease. This manifests itself either in the form of urticaria, or by effusion into joints, and slight pyrexia, the latter symptom being perhaps the more frequent. If the administration be continued, it has been asserted by some that anaphylactic symptoms, albuminuria, and other complications, are apt to follow. We may repeat that we have never seen such a result in thousands of cases.

Urticarial rashes very soon disappear after the exhibition of calomel followed by a dose of salts, and joint effusions also rapidly subside under the same treatment.

We would, however, mention that in the case of wounds of large joints we do not, unless the joint is grossly infected, repeat the administration of the serum. We think this is justifiable, because synovial sacs possess a greater immunity from infection than other tissues, and further, in six

cases of knee-joint injuries which were doing well and showing normal temperatures at the end of the tenth day, a second dose of serum was given. This course was adopted because the wound in the skin, which was open, was not quite clean. The result in every case was an effusion into the damaged joint, and in four of these cases the effusion became slightly infected, necessitating repeated aspiration. Recovery followed, however, and good movable joints resulted. The remaining two cases showed an effusion, which subsided, but which caused us many anxious moments. This was a lesson, and now, gaining by this experience, we never administer a second dose of serum to any case of injury of a large joint unless the joint is grossly infected.

Treatment of Established Tetanus.—When tetanus symptoms, either early or late, become established, most energetic measures must be taken. The earlier the treatment is commenced, the better the patient's chances of recovery ; hence no time must be lost.

The patient should be removed at once to a quiet ward, allowed no visitors, and should be kept shaded from the light. All requisite nursing should be carried out as quickly as possible, for it must be remembered that any small stimulus is quite sufficient to induce a spasm. Washing and any necessary attention should therefore be performed quietly, quickly, and deftly. The temperature should never be taken by mouth, owing to the danger of breaking the thermometer, but should always be taken in the axilla or the groin.

Feeding the patient is very important, though difficult. The food should consist of nourishing fluids, such as egg-flip, beef-tea, jellies, and the like, given frequently between the spasms, for it is very important at this stage to maintain the patient's strength and resistance. If unfed, these patients rapidly waste, and their chances of recovery are seriously jeopardised. Nasal feeding should never be practised. On no account should these patients be fed by rectum. The act of performing this is quite sufficient to induce a spasm, which not only further distresses the patient, but results in all the rectal feed being immediately expelled.

The bowels should be kept moving by means of aperients, and of these the saline purgatives are preferable. Enemata should not be given, as they only result in inducing another spasm.

The floor of the ward should be covered with linoleum or some kind of fabric, to damp all noise of footsteps, and doors should be opened and closed as quietly as possible. Stimulants should be avoided.

Surgical treatment aims at removing the cause. The wound, if dirty, should be widely excised under chloroform anæsthesia, and active sterilisation of the excised wound should be carried out by means of the Carrel-Dakin or some other suitable and efficient method. We particularly recommend Carrel's method, as the dressing need only be changed every second day, and it is perfectly painless. It is advisable to give ¼ grain of morphia half an hour before changing the dressing.

Antitetanic serum should be administered freely intrathecally, intravenously, and subcutaneously. One thousand five hundred units or more may be given at one sitting intrathecally, and this may be repeated at the end of twenty-four hours. At the same time 1,000 units may be administered intravenously, and another 1,000 units subcutaneously, and this also may be repeated at the end of twenty-four hours. If after three such administrations the symptoms are tending to subside, the spasms becoming less frequent and of less severity, then 500 to 1,000 units may be given subcutaneously daily for the next five or six days. In two cases we have injected the serum into the cerebral meninges. The procedure consists in making two small trephine holes, one over each frontal lobe, and very slowly running in 250 units on each side through a needle which is made to penetrate the meninges. This was combined with subcutaneous administration, and both cases recovered.

For control of the spasms various measures have been suggested. Good results have been reported from the injection of a solution of magnesium sulphate intrathecally, but we have never tried this. Morphia, a mixture of bromide and chloral, with an occasional few whiffs of chloroform, are usually sufficient to control or profoundly modify the spasms. The patient's colour must be watched. Should he become cyanosed, with an irregular pulse, it may be that too much hypnotic has been administered and so stimulant treatment under these conditions is called for.

CHAPTER IX

GENERAL COMPLICATIONS OF WOUNDS (*Continued*)

Secondary Hæmorrhage.

SECONDARY hæmorrhage has been a frequent complication of gunshot wounds. It may appear as early as the fifth day, or it may be delayed as late as the twentieth day after infliction of the wound.

In a series of 1,000 consecutive cases of serious gunshot wounds, secondary hæmorrhage occurred in twenty-five. This gives a percentage of 2·5. Of these twenty-five cases eight died, giving a mortality of 0·8 per cent. Ten of the twenty-five cases had been submitted to amputation by the guillotine method through the lower third of the thigh at the casualty clearing station, and the amputations had been carried out through infected tissues. Eusol dressings had been applied, and advanced sepsis was present in the stumps when the base hospital was reached.

Of the remaining fifteen cases, hæmorrhage occurred from open amputation stumps in three, and here the amputation had of necessity to be performed through flaps infected with gas gangrene. Two cases were the result of an imperfectly reduced compound fracture of the femur, and one of an imperfectly reduced compound fracture of the humerus. Two occurred as the result of the giving way of an arterio-venous aneurysm in the thigh, and the remainder were confined to extensive comminuted fracture of bones of the leg (five cases) and compound comminution of bones around the elbow-joint (two cases), where the common interosseous artery was involved.

CAUSES OF SECONDARY HÆMORRHAGE

Predisposing causes are—

(1) Infection.
(2) Mechanical.

Exciting causes are—

(1) Constipation.
(2) An irritating cough (usually due to pulmonary embolism, and not infrequently associated with compound fracture of bone, especially of the femur).
(3) Giving of stimulants and too liberal a diet.

Infection.—When infection exists in a wound, a catgut ligature soon dissolves, and at the same time the thrombus in the end of a divided vessel becomes digested and broken up. Infection further tends to constipation and to the dissemination of emboli. There is no doubt that the presence of sepsis in a wound is, above all, the most potent factor in the production of secondary hæmorrhage

Mechanical.—Secondary hæmorrhage has resulted from the imperfect reduction of a compound fracture. The unreduced ends of the fractured bone, by exerting pressure upon an artery, erode it, and hæmorrhage results. It is very important to procure as perfect a reduction as possible in the case of all compound fractures of long bones, and any rough fragments or ends of fractured bone should be carefully manipulated from the neighbourhood of a large artery or vein after the wound has been excised. This done the limb should be thoroughly immobilised prior to the application of a Carrel-Dakin dressing, and the surgeon should not apply such a dressing until he has convinced himself that the splinting apparatus employed is certain to maintain the reduction he has already effected. It sometimes happens that when a bone is badly comminuted and splintered, very small fragments are widely disseminated amongst the surrounding tissues. One of these fragments, which can very easily escape the eye of the surgeon, may be the cause of a secondary hæmorrhage, although the main fracture be satisfactorily reduced. This unfortunate occurrence, though rare, has happened, and it should always be borne in mind. Carrel's tubes should never be allowed to rest against a vessel, for an artery is rapidly eroded by such means, and secondary hæmorrhage results.

Constipation.—Straining at stool has brought about secondary hæmorrhage, not only at the time of performing defæcation but also shortly afterwards. The act of passing a constipated stool puts considerable strain on a ligature, which, if applied to an artery in tissues that are infected, is very apt to give way.

An Irritating Cough.—A patient suffering with a constant irritating cough is continually putting strain on a ligature, and the time comes when either the ligature gives way or the artery wall just above it.

Cough, the result of pulmonary embolism, was not at all an infrequent complication of septic compound fractures of bones, especially of the femur, and secondary hæmorrhage was the dreaded result. Even after amputation, emboli have travelled to the lung, and, by giving rise to a constant painful cough, have produced serious secondary hæmorrhage from the stump. Fortunately, since the Carrel-Dakin treatment has been established we very rarely now see embolism.

Stimulants and too Liberal a Diet.—Stimulants, by raising the blood-pressure, tend to cause secondary hæmorrhage, and a too liberal diet will produce the same effect. These should be carefully avoided until all risk of secondary hæmorrhage has passed.

Effects of Secondary Hæmorrhage on the Individual.

Secondary hæmorrhage forms only a part of a vicious circle, and from what has been already said it will be understood that the only cause of secondary hæmorrhage, other than mechanical causes, is *sepsis*. Sepsis is responsible for by far the greater percentage of all cases of secondary hæmorrhage.

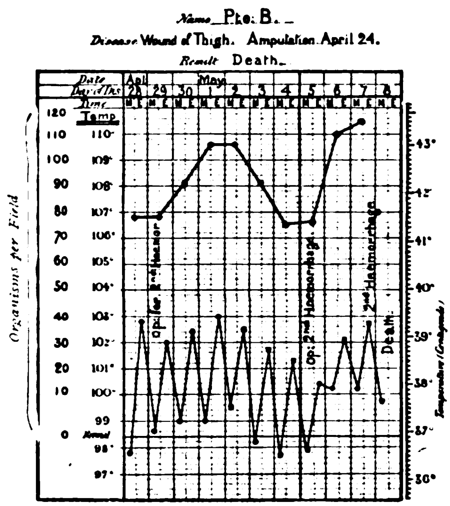


FIG. 42.—Case of recurring secondary hæmorrhage.

Lower tracing denotes temperature; upper tracing denotes organisms per field. Note the increase in organisms per field after each hæmorrhage, and the consequent steady rise of temperature. Gangrene commenced in the stump just before death.

The direct effect of a secondary hæmorrhage on the individual is to lower his resistance further, the degree varying with the amount of blood lost. Secondary hæmorrhage invariably occurs at a time when a wounded man can ill afford to lose any blood at all—that is, on about the tenth day after the wound was inflicted. With a still lower resistance brought about by the secondary hæmorrhage is associated an increase of spread and virulence of infection, this latter in turn being the cause of another hæmorrhage a day or two after the bleeding vessel has been religatured. The result of this last hæmorrhage is again to enhance the virulence and spread of the existing infection, and so the vicious circle goes on.

In the case of repeated hæmorrhages, the interval of time between each succeeding hæmorrhage and the ligature for the arrest of the preceding one gets shorter and shorter. This is explained by the increase in sepsis brought about by a proportionately lowered resistance.

One example will suffice to make this point more clear:

Pte. ——, 7th Royal Berks, was wounded on May 9, 1917. His right lower extremity was amputated at a casualty clearing station on the same

day, owing to excessive comminution of the bones entering into the formation of the knee-joint, and a eusol dressing was applied. He had already suffered severe hæmorrhage during transit from the battlefield to the casualty clearing station. On arrival at the base hospital on May 12, the amputation stump was very septic. A Carrel-Dakin dressing was applied, but on May 14—that is, on the sixth day after his wound—he had a severe secondary hæmorrhage from the femoral artery. The artery was immediately religatured in the stump. The stump during the next two days was extremely dirty and septic, showing no tendency to clean, despite every effort to sterilise it. At the end of the second day following religature, there was another hæmorrhage from the same vessel, which was again religatured after further dissecting it up in the stump. The patient's general condition during the next twenty-four hours was grave, and the local condition remained apparently stationary. It was at this time that he had a third hæmorrhage from the same artery, and although religatured for the third time, he died eighteen hours later.

Secondary hæmorrhage, by its lowering effect on the general resistance, is often responsible for the onset of general septicæmia and pyæmia.

We may quote one instance out of a few to demonstrate this:

Sergeant ——, wounded on April 24, 1917, sustained a severe compound fracture of his right femur. The wound was thoroughly excised, a Carrel-Dakin dressing applied, and the fracture was, as far as we could make out, satisfactorily reduced. All went well for twelve days, and for five days the temperature and pulse were normal and the wound clean, the bacterial count being 5 per field. Without any warning, on the twelfth day an extensive hæmorrhage developed from the profunda femoris artery, due to pressure on it of an unnoticed spicule of bone. The artery was tied and the patient put back to bed.

Four days later the temperature rose in the evening to 103° F., returning to just above normal in the morning, and this continued to be the case for a week, when a blood culture showed the presence of *Streptococcus pyogenes* in the circulation. The wound became again highly infected, showing over one hundred organisms per field, chiefly streptococci, *B. coli*, and *B. perfringens*. Active sterilisation of the wound was persevered with, and an autogenous vaccine made from the blood organisms was administered along with antistreptococcal serum. The temperature gradually fell, and was normal again at the end of the third week. The patient made a good recovery.

Another case of interest is that of Pte. ——, wounded on May 5, 1917, who sustained a compound comminuted fracture of the right tibia. He progressed well up to the ninth day, when he had a secondary hæmorrhage from the anterior tibial artery, the result of an imperfectly reduced fracture. Four days after arrest of the hæmorrhage the wound showed a count of 50 organisms per field, though two days before the hæmorrhage occurred the count was 2 to 3 fields. In the grossly infected wound

coliform bacilli were present in considerable numbers. On the fourth evening following the hæmorrhage the temperature reached 102·5°, returning to 101° in the morning. A blood culture showed the presence of a coliform bacillus in the circulation. No vaccine was given, but at the end of the tenth day the temperature returned to normal, and five days later the wound was sutured, the count being 2 per 5 fields. It is interesting to note that this patient had suffered from dysentery in the preceding year, and after the secondary hæmorrhage he suffered from diarrhœa and mucus in the stools. This is only one out of a number of similar cases, and goes to prove that a secondary hæmorrhage influences for the worse not only a recent wound, but also such conditions as a chronic ulcer or ulcers in the intestine. Septicæmia in which a blood examination has revealed the presence of coliform bacilli in the circulation have not in our experience been infrequent. The patients have all been the victims of previous dysentery or diarrhœa, and the nature of the temperature, and the general aspect of the patient, have often suggested an attack of paratyphoid. A Widal reaction has proved this to be negative ; the temperature lasts for ten days only, by which time the blood infection seems to disappear. The course of such a septicæmia is very typical, and we can often recognise the condition from the temperature chart alone. In three cases where the urine was examined the same bacillus was present. This type of septicæmia does not seem to give rise to noticeable constitutional symptoms, nor does it materially impede the sterilisation of a wound. From our experience we can say that the condition has proved practically harmless.

Malaria and Secondary Hæmorrhage.—On the Balkan front secondary hæmorrhage may precipitate an attack of malaria, and this has occurred in patients who can give no previous history of an attack.

Malaria following a secondary hæmorrhage is a severe complication in the case of any wound, and though it may not necessarily threaten life, yet it puts the wound back for weeks. Such wounds are notoriously indolent and very slow to sterilise.

Although the effects of malaria complicating wounds are described by Lieut.-Colonel L. F. Smith in another chapter, we do not think it is out of place to refer to it here also in this connection. We have constantly seen wounds that have assumed a very typical appearance, especially after a hæmorrhage, though the same characters may be present in the wound of a patient who has suffered a number of previous malarial attacks. This particular class of wound strongly resembles a gumma. It takes on the appearance of a large or small ulcer with deep punched-out edges. The serpiginous character of the edges may or may not be present, the ulcer itself shows no tendency to spread, its base is dry and greyish, secreting but little, and covered with a glairy mucoid membrane.

Two cases will suffice to illustrate this :

Lieut. —— had nine consecutive attacks of malaria. He had for years

been possessed of a sebaceous cyst the size of a pigeon's egg, and situated over the right scapula. While in hospital after the ninth attack of malaria, the sebaceous cyst suppurated. An incision was made to evacuate its contents, the cyst lining was removed, and the wound left to granulate. This patient was extremely anæmic, showing well-established malarial cachexia. He was given quinine gr. xl. daily by mouth, but despite this at the end of seven days after operation the wound resembled most typically a tertiary ulcer. It was not until he was given quinine gr. xxx. intramuscularly each day that his general condition started to improve and the wound became healthy and healed.

Pte. ——, wounded by high explosive on October 16, 1917, had his left knee-joint perforated. The wound of entry was in the popliteal space, damaging the popliteal vein, while the wound of exit was on the outer aspect of the joint. The popliteal vein was ligatured at the casualty clearing station. On arrival at the base hospital he had a secondary hæmorrhage. The vessel was ligatured, the wounds excised and sutured. The hæmorrhage and operation were followed by an attack of cerebral malaria. Part of the wound on the outer aspect of the joint which was sutured broke down, and in many ways resembled a tertiary syphilitic ulcer, and this despite the fact that he was taking quinine gr. xxx. by mouth daily. Quinine gr. xl. given intramuscularly on each of five consecutive days sufficed to bring about a great change for the better in the general condition, and the wound rapidly healed. He has now a perfectly movable and sound knee-joint.

In neither of the above cases was the malarial parasite found, but this may be explained by the fact that both patients were taking quinine by mouth when their blood was examined. A blood-count in both cases, however, showed 40 per cent. and 43 per cent. of lymphocytes respectively.

We might mention here the important fact that an attack of malaria can be responsible for a secondary hæmorrhage, though in our experience this has been rare, as all wounded men in the Balkans are systematically given quinine throughout their treatment.

It is of interest that a percentage of wounds inflicted on men who have suffered repeated attacks of malaria are extremely indolent, although these men are taking large doses of quinine by mouth and are apparently absorbing it, for they show a clean tongue and no digestive disturbances. If the quinine by mouth be stopped, then within forty-eight hours an attack of malaria invariably follows. If the quinine by mouth be continued the wound still remains indolent, but the patient has no further attacks of malaria. If, however, the quinine be administered intramuscularly, the wound assumes a healthy appearance, sterilises quickly, and can be sutured.

Though the treatment of malaria does not come within our province, yet malaria in the Balkans is so frequent a complication of wounds that we do not think it out of place here to mention that, judging from our observations on wounds alone in a country where a malignant type of malaria

abounds, we have come to the following conclusion : A patient who has had one or more attacks of malaria may, by taking quinine by mouth, appear healthy and free from the disease. His tissues nevertheless, as exhibited in wounds, are anything but healthy, and a cessation of the drug for forty-eight hours has been quite sufficient to allow of another attack occurring, although he has been taking large doses daily for as long as three weeks. If, however, four or five consecutive doses of intramuscular quinine be given, and this followed by quinine by mouth, the tissues of the wound assume a normal healthy aspect and there is a marked change in the wounded man's general condition. Further, the wound rapidly sterilises, and can be sutured.

So striking and constant have these observations been that we now regularly give severely wounded men on this front intramuscular quinine, followed by quinine by mouth. Again, though physicians may not agree, we would, in the event of again contracting malaria, first treat ourselves with intramuscular quinine, and follow it up with quinine by mouth.

Pathology of Secondary Hæmorrhage.—There is little to say on the pathology of secondary hæmorrhage, as this is so well known. When an artery is divided and ligatured a clot forms in the end of the ligatured vessel, which undergoes organisation into fibrous tissue. Should sepsis, however, be present, the thrombus, instead of becoming organised, breaks down, the ligature and part of the artery wall slough away, and hæmorrhage results. When once this has occurred, the artery wall for some distance into the stump is inflamed and friable ; hence it is most important before applying a second ligature to dissect out the artery well up into the stump until a sound part of its wall is reached.

When secondary hæmorrhage occurs as a result of mechanical causes, such as pressure exerted on the artery by a rough piece of bone or a Carrel's tube, it is simply a question of erosion of the artery wall.

Treatment.—Successful treatment is prophylactic, and this aims at subduing infection. Fortunately, since excision of wounds followed by primary suture or the application of a Carrel-Dakin dressing and later secondary suture has been practised, secondary hæmorrhage has become more and more rare, and now promises to become an event of the past.

Most secondary hæmorrhages in our experience have resulted from open amputation stumps and septic compound fractures of bone which have been imperfectly reduced. When amputation by the guillotine method or open flaps is necessary, a double ligature of catgut should be applied to the main vessels. Silk should not be used, as the hypochlorites rapidly destroy it. When the amputation is complete, a Carrel-Dakin dressing should be employed and vigorous sterilisation of the stump carried out. Whenever a Carrel-Dakin dressing has been immediately applied after amputation at the casualty clearing stations there has been no further trouble, as the stump has rapidly sterilised and been submitted to secondary suture on the tenth to the twelfth day.

An ordinary eusol dressing applied to open amputation stumps is useless, as it loses its bactericidal power in from one to two hours. Salt packs are little better, as they, again, exert no bactericidal effect on badly infected tissue.

Earlier in this campaign, before the Carrel-Dakin treatment was established, open amputation stumps arriving at the base with eusol dressings applied became a nightmare. On removing the dressing the main artery could be seen pulsating in the septic stump with a slough on the end of it. This always meant only a question of hours before the slough separated and secondary hæmorrhage resulted. Latterly we did not wait for this to happen, but in every case we religatured and applied a Carrel-Dakin dressing, using hourly instillations of the antiseptic. With this treatment there was no more trouble. In the case of extensive compound fractures there is both infection and displacement of bone to consider. When once the wound has been thoroughly excised the fracture should be reduced, and all rough pieces of bone removed from the line of the main vessels and kept away by suitably applied extension. No surgeon should be content until he is perfectly certain that he has accomplished this. This done, a Carrel-Dakin dressing is applied and sterilisation of the wound proceeded with. Cases of a most extensive nature so treated have given rise to no trouble from secondary hæmorrhage.

Fortunately, most cases of secondary hæmorrhage are preceded by an aura. There is usually some oozing of blood through the dressings. This should always be an indication for immediately taking down the dressing and doing what is necessary. For this reason no bed-clothes should ever be allowed to cover an amputation stump or severe wound of the arm or leg until the time for secondary hæmorrhage has passed. By leaving the dressings uncovered, the wounded man's next-door neighbour, the orderly, or the sister, will immediately detect the staining of the dressing and send at once for the medical officer. Any patient possessing a wound that is liable to secondary hæmorrhage should have a tourniquet hung above his bed.

In addition to oozing of blood through the dressing, there is often a rise of 2° in the temperature, with a rise in the pulse-rate. Should these three auræ coexist, they are ominous of a secondary hæmorrhage, and necessary surgical measures should be taken at once before the hæmorrhage develops.

These auræ do not call for the immediate use of the tourniquet. Sisters should be instructed to raise the foot of the bed if the lower extremity be involved, and to elevate the upper extremity if this be involved, and to retain it elevated until the medical officer arrives. Morphia gr. $\frac{1}{4}$ or $\frac{1}{2}$ with atropin gr. $\frac{1}{100}$ should be given hypodermically as soon as possible and the patient removed to the theatre. Should hæmorrhage develop, the tourniquet must be applied immediately, as digital compression of an artery by a sister is unreliable. Many tourniquets are at present in use, but two of

the most suitable are those devised by Adams and Fiddian, as shown in the illustrations on p. 254.

Should a considerable hæmorrhage have taken place in the ward, the patient, if possible, should not be allowed to see it; but if he has already done so, he should be assured that it is nothing of a serious nature. It is important to remember this, as a hæmorrhage is exceedingly terrifying to a patient, and it exerts a bad influence on his mental condition.

Secondary hæmorrhage must be checked at once, for loss of blood to a wounded man at this stage, if not immediately fatal, is the forerunner of serious complications of a septic character.

Operative Treatment.—Hæmorrhage from open amputation stumps requires religature of the bleeding vessel. After applying the tourniquet, the bleeding vessel, usually the main artery, must be dissected up, and the surgeon must not stop until he has reached a healthy non-inflamed and non-friable part of the artery wall. This dissection should be carried out quickly and with as little disturbance as possible to the remaining tissues in the stump, in order to prevent any further dissemination of infection. When once healthy artery wall is reached a double ligature of either stout catgut or kangaroo tendon is applied. Silk should not be used, as the hypochlorites destroy it. If the condition of the artery wall be doubtful, then we would recommend a petticoat of muscle or other tissue being left around it prior to applying the ligature. On no account, except in certain situations, should the artery be ligatured through a separate incision in apparently sound tissues, for hæmorrhage will certainly recur. By ligaturing an artery higher up, the vitality of the already infected stump is further lowered and the infection thereby increased. The result of such a procedure is therefore to favour another hæmorrhage.

Should hæmorrhage occur from a damaged artery in the thigh or upper arm, the result of a compound fracture, the wound should be widely opened up and the divided ends of the damaged vessel exposed, clamped, and ligatured in as sound tissue as possible. To apply proximal ligature is useless in these situations.

Should hæmorrhage occur from the popliteal vessels, a departure from what has been said above should be practised. Experience has taught us that ligature of the popliteal vessels for gunshot wounds, in a great number of cases, is followed by gangrene of the limb below the ligature. In such cases ligature of the artery in Hunter's canal or the apex of Scarpa's triangle has been the operation which has given the best results.

Should hæmorrhage be coming from the forearm or leg, and be associated with injury to the common interosseous vessels, the peroneal, the posterior tibial, or the anterior or posterior interosseous arteries of the forearm, these cases are often most difficult to deal with. In a number of cases treated at one of the casualty clearing stations in France ligature of the posterior tibial artery was followed by gangrene of the foot necessitating amputation, and further, if this artery be successfully ligatured, hæmor-

rhage, for some reason, is very prone to recur. The same remark applies to the interosseous arteries of the forearm. In ligaturing these vessels the surgeon must not be guided by classical incisions. It is quicker and more practical to enlarge the original wound freely while a tourniquet is applied, and with a good light and retraction to find the ends of the vessel. It will often be the surgeon's experience to find the vessel at some distance from its normal anatomical position, having been displaced by the missile.

Both ends of the divided vessel must be ligatured, or hæmorrhage will recur. Should there be extensive damage to bone in the forearm or leg, associated with uncontrollable secondary hæmorrhage, we have had excellent results from ligature of the brachial artery just above the head of the elbow if the forearm be involved, and the femoral artery in Hunter's canal if the leg be involved.

Secondary hæmorrhage from the palmar or plantar arches is most difficult to treat. We have been concerned with a number of such cases, and have found the most satisfactory solution is to make a free incision into the palm or sole and ligature the divided vessel. We have tried ligature of the posterior tibial vessel below the internal malleolus, and also ligature of the ulnar and radial arteries, and in two cases have seen gangrene of the ends of the fingers follow, with a recurrence of the hæmorrhage. Ligature of the divided ends of the arch, though often a long and tedious operation, has given the most satisfactory and best results.

We have confined our remarks chiefly to secondary hæmorrhage occurring in the extremities, as these are the commonest sites, but the surgeon must be prepared to find and deal with it anywhere.

We may quote one case out of a number to illustrate this:

Pte. ——, wounded on September 20, 1917, sustained a compound fracture of the right iliac bone. He progressed favourably up to the eighth day, when he contracted a third attack of malaria. On the tenth day there was a hæmorrhage from the wound in the right buttock and pain in the right iliac fossa. Examination showed a large tender swelling to be present in this situation. The swelling was approached extraperitoneally, and it was found that hæmorrhage was taking place from the iliac branch of the ilio-lumbar artery. A ligature was applied and disinfection of the wound carried out.

Secondary hæmorrhage from the sciatic or gluteal arteries in the case of large buttock wounds has occurred, and no part of the body where septic wounds exist is exempt from this complication.

Instances in which mechanical causes more than infective causes were giving rise to the hæmorrhage have proved satisfactory with a five days' salt pack. The pack should be applied in such a way that it is sufficient by pressure to control the hæmorrhage from the wound, without interfering with the general circulation of the limb.

After ligature of the damaged vessel, energetic measures towards

sterilising the wound by the Carrel-Dakin method must be taken in order to prevent a further hæmorrhage.

In all cases of hæmorrhage we have ligatured both artery and vein.

After-Treatment.—The cases receive hourly instillation of the hypochlorite solution and the following mixture by mouth three times a day :

Mag. sulph.	...	...	...	...	grs. lx.
Pot. brom.	...	...	...	...	„ xx.
Calcii chlorid.	...	...	...	...	„ x.
		Aquam.			

All stimulants are carefully avoided, and should a cough develop opium is the best remedy.

Should a severe hæmorrhage occur, saline solution by rectum six-hourly with 1 or 2 pints containing bicarbonate of soda given subcutaneously in the theatre during operation is recommended.

Morphia may be given freely for the first day or two to ensure rest and keep the blood-pressure low. Direct blood transfusion in bad cases has given excellent results, and as much as 2 pints may be given without causing any bad effects in the donor. Unfortunately, in the Balkans, where malaria abounds, it is not always easy to find a healthy donor.

Active sterilisation of the wounds is of supreme importance, and it should be thoroughly seen to that every part of an open amputation stump or large wound receives an hourly and adequate supply of the antiseptic.

CHAPTER X

SEPTICÆMIA AND PYÆMIA

SEPTICÆMIA and pyæmia occurring as complications of gunshot wounds should always be investigated bacteriologically. An attempt should be made in every case to isolate the causal organism, in order that, if necessary, an autogenous vaccine may be prepared and specific treatment carried out.

The various types of septicæmia and pyæmia which the authors have met with as direct complications of wounds are as follows :

1. Streptococcal type.
2. Coliform type.
3. Gas-gangrene type.
4. Mixed type.

In addition, a diphtheroid type of septicæmia is said to occur, but we have not seen a case.

In a series of twenty-four cases of septicæmia in which the causal organisms were found by bacteriological examination, the types were distributed as follows :

1. Streptococcal type ...	long-chained streptococcus (*pyogenes*) ...	10 cases.
	short-chained „ (*fæcalis*) ...	1 case.
2. Coliform type ...	*B. coli* (typical)	1 case.
	coliform bacilli (various)	4 cases.
3. Gas-gangrene type ...	*B. perfringens*	5 cases.
4. Mixed type ...	streptococcus and coliform bacillus ...	2 cases.
	streptococcus and *B. perfringens*	1 case.
		24 cases.

The causal organisms may be isolated (1) from the blood, (2) from the urine, (3) from pyæmic abscesses. The first is by far the most satisfactory source, and wherever septicæmia is suspected a blood culture should be performed.

Methods of Examination

From the Blood.—The skin in front of the elbow or over any large vein is very carefully sterilised by the application of spirit soap, followed by ether, and then by several applications of iodine. Any other efficient

method of sterilising the skin may, of course, be adopted, but it is absolutely essential to use the greatest care on this point, as contaminations are very liable to appear in a blood culture. Bacteriological asepsis, not merely surgical, must be secured.

The veins at the elbow are rendered turgid by the firm application of a piece of bandage or rubber tubing to the upper arm. A 10 c.c. or 20 c.c. all-glass syringe is used. It should be sterilised with needle and all other parts *in situ*, the whole being enclosed in a large glass test-tube (see Fig. 43). The sterilisation of the whole apparatus should be performed in the hot-air oven at 140° C. for three-quarters of an hour. If this procedure be followed there is no risk of contamination from the operator's hands.

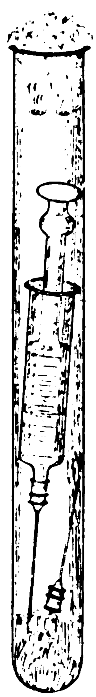


FIG. 43.—Method of sterilising syringe for hæmoculture.

Sterilisation should be effected in the hot-air chamber at 140° C. for one hour, or 150° C. for half an hour.

The needle of the syringe is passed through the skin into the subcutaneous tissue overlying the median basilic vein. A pause is made to secure direct alignment of the needle and vein, and the point of the needle is then plunged sharply into the vein strictly in the direction of its long axis. An attempt should never be made to pass the needle into the vein by a single sudden plunge from the outside. This part of the procedure never fails when performed in two stages as described. Blood flows at once into the syringe, often under sufficient pressure to force the piston along the barrel. About 10 c.c. of blood are withdrawn and distributed equally among three or more large tubes or small flasks of media, each containing 20 to 50 c.c.

The culture media which we have found most useful are—

(1) Trypsin broth (Douglas).
(2) The same, with the addition of 5 per cent. saline pea extract.
(3) Litmus milk. (See pp. 72 and 73.)

An assistant should be at hand to hold these tubes or flasks and withdraw rapidly the cotton-wool plugs in turn, while the operator inserts 3 or 4 c.c. of blood into each. This must be done rapidly, or the blood will coagulate in the syringe. The cotton-wool plugs should be replaced as quickly as possible, to prevent contaminations with air organisms.

The culture tubes are incubated at 37° C. overnight, and then examined and subcultured according to the usual methods.

From the Urine.—A sterile catheter specimen must be used. The meatus and glans penis are thoroughly cleansed with eusol before the passage of the sterile catheter. The first part of the urine is rejected, and that flowing towards the end of micturition is caught in a large sterile tube. About 10 c.c. of this urine is pipetted with aseptic precautions into large tubes of (1) trypsin broth, (2) pea-extract broth, and (3) 2 per cent. sodium taurocholate peptone-water, in cases where coliform organisms are suspected to be present.

Direct plate cultures may also be made by pouring the urine over plates of trypagar or of MacConkey agar, according to the type of organisms believed to be present.

The examination of the urine in septicæmia is of use in various ways—*e.g.*, (1) in a case of septicæmia of the mixed type, when one or other of the organisms may be more easily recovered in pure culture than from the blood; (2) in lasting cases of septicæmia, late in the disease, when the organisms may be more readily recovered from the urine than from the blood; and (3) to confirm the hæmocultural findings.

From Pyæmic Abscesses.—Direct tube or plate culture from the pus on trypagar or brain agar is often sufficient. It may be necessary in some cases to inoculate animals, and recover the organism from the blood or lesions.

Pyæmic abscesses are often said to be sterile, and it is true that the causal organism, which is usually *Streptococcus pyogenes*, very frequently fails to grow upon the ordinary media in direct primary culture from the pus. Growths can, however, usually be obtained by the employment of the enriched protein media named above.

Cultivations from pyæmic abscesses may be of use (1) in obtaining growths of the causal organism of the septicæmia, where the method of blood culture fails; (2) where the abscess-infection is a mixed one, as in abscess of the lung. In the latter case it is desirable to obtain growths of the other pathogenic organisms which can be isolated from the purulent matter in the sputum, in order that all of them may be included in the therapeutic vaccine.

1. Streptococcal Type

This is the most common type of septicæmia complicating wounds, and a very fatal one. Fortunately, the introduction of the Carrel-Dakin treatment of wounds, and more recently of a more satisfactory method of treating penetrating wounds of the knee-joint, has coincided with a greatly diminished incidence of the disease.

The types of wound with which it is most frequently associated are septic compound fractures and septic wounds of joints, especially the knee-joint; very rarely it occurs in connection with simple flesh wounds.

Out of the fourteen cases in which a streptococcus alone or in combina-

tion with other organisms was found in the above series, the following types of wounds were present:

Compound fractures..	8 cases
Penetrating wounds of knee-joint	5 cases
Pyopneumothorax	1 case
	14 cases

Pathology.—The disease is almost invariably associated with bone lesions. All but a very small minority occur in cases of compound fracture or of septic joints. In the latter cases the septicæmia does not occur until the articular cartilages are ulcerated and the cancellous tissue of the underlying bone is exposed. The organism appears to gain entrance somewhat readily to the blood-stream in cancellous bone. Lack of thorough immobilisation of the fracture or joint is undoubtedly a potent predisposing cause, and probably acts mechanically by tearing open the mouths of the minute vessels of the bone. Secondary hæmorrhage, by diminishing the patient's resistance, is also an important predisposing cause. Inefficiently treated sepsis in wounds is, of course, a most potent factor in the ætiology.

The organism was found by blood culture in ten out of the fourteen cases; in two cases (verified post mortem) the blood cultures during life were sterile; in the remaining two cases blood culture was not performed and the organism was recovered pure from pyæmic abscesses. In all cases but one the organism formed long chains in fluid media and grew in minute discrete colonies upon trypagar and brain agar. The carbohydrate reactions were not quite constant. Acid-production in mannite, saccharose, and lactose, with acid in litmus milk, and no reduction of neutral red, were constant in all but two strains; the latter failed to ferment mannite and saccharose. The reaction to glucose was negative in all but two strains, and in these acid was produced. All these organisms (except one) were taken to belong to the *Streptococcus pyogenes* group. This exception was an organism which formed very short chains in fluid media and gave the reactions of *Streptococcus fæcalis*. No corresponding difference in the clinical appearances of the septicæmia produced by this organism and that by the *Streptococcus pyogenes* group was noted. The former was equally virulent, and was, indeed, in this particular instance fatal.

Clinical Appearances.—From a consideration of our cases there appear to be two chief clinical modes of onset:

(1) *Sudden onset*, at a variable period after the infliction of the wound.
(2) *Gradual onset*, after a prolonged period of toxæmia.

(1) This is the common form. The wound, which is in many cases a compound fracture, may appear to be progressing favourably, when suddenly the temperature begins to show an evening rise to 103° or 104° F. This occurs at a period varying from three to twenty-one days after the

infliction of the wound. In our cases the average time was fourteen days. The patient, at first, does not look very ill, pulse is generally good and tongue clean, and there are no alarming symptoms. For this reason the condition is often not suspected until the disease is well advanced. The course of the disease is variable, but usually lasts, in fatal cases, two to five

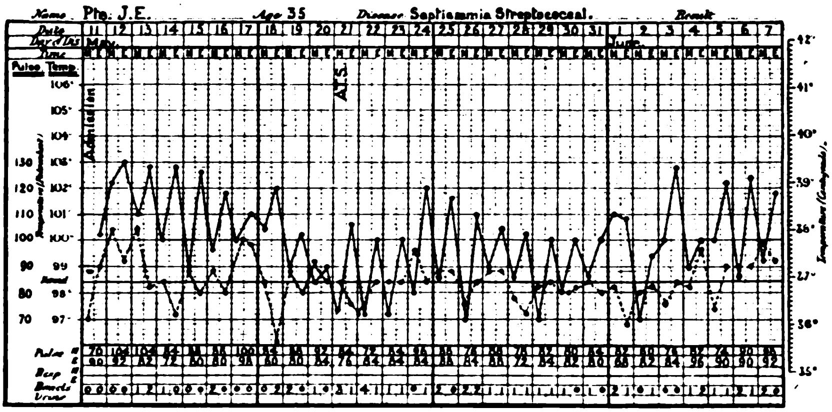


FIG. 44.—Streptococcal septicæmia.
Streptococcus pyogenes obtained by hæmoculture.

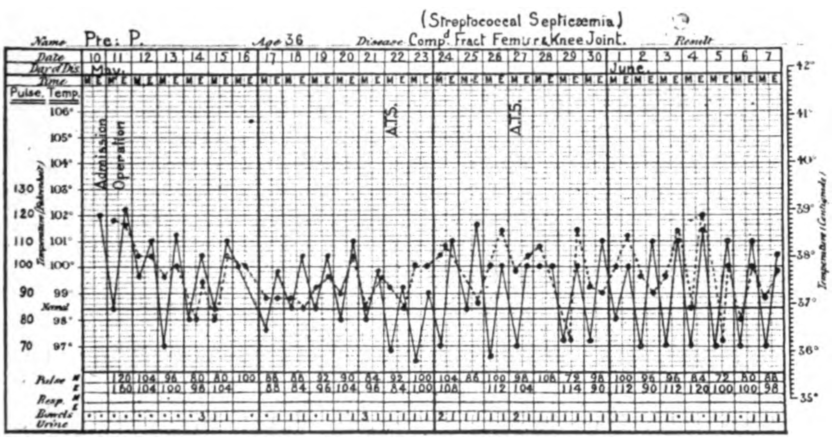


FIG. 45.—Streptococcal septicæmia.
Streptococcus pyogenes obtained by hæmoculture.

weeks, depending upon where and when the pyæmic abscesses occur. If the lung becomes involved early, the course is comparatively short. The lung becomes involved sooner or later in nearly all cases. In two cases the disease was fatal in less than a week, one of them having a pyæmic purulent pericarditis. As the disease progresses, the appearance becomes more typical, and gradually the syndrome of symptoms mentioned below

make their appearance. They are observed in nearly all fatal cases within a few days or even a week or two of death.

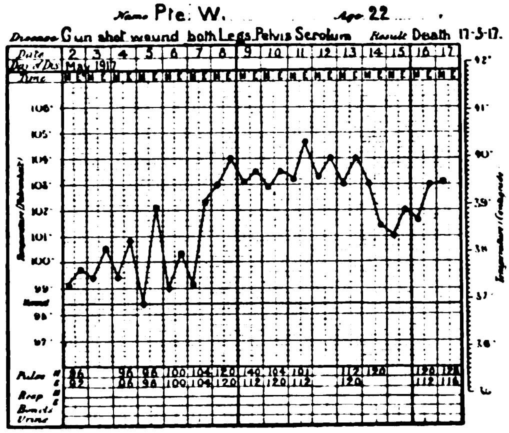


FIG. 46.—Streptococcal septicæmia.
Sudden onset, short course.

(2) The *gradual onset* is less common, because radical treatment for the toxæmia serves in many cases to avert the condition. In this type the wounds are always very septic. There may be a large septic surface as in pyopneumothorax, or there may be a spread of the infection to neigh-

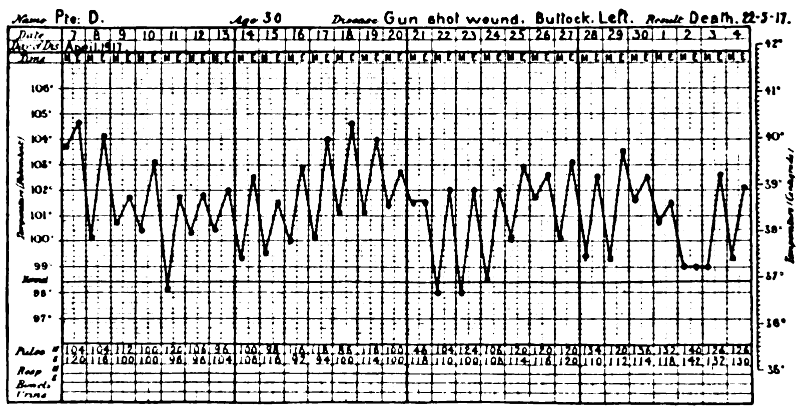


FIG. 47.—Streptococcal septicæmia.
Gradual onset, prolonged course. Note high remittent character of temperature.

bouring structures, such as joints or bone (acute osteomyelitis), or there may be unremoved foreign bodies or pieces of necrosed bone in the wound or multiple septic wounds. These conditions cause retention of pus, with septic absorption and prolonged toxæmia. Unless the cause of the toxæmia can be discovered and removed, septicæmia may ensue after a

long period. The onset of the septicæmia is marked by a change in the patient's general condition. The temperature may become continuously high and remittent, and the pulse more rapid and weak; the tongue, at first clean, becomes dry and fissured. The patient emaciates rapidly, and death occurs within one to three weeks of the onset.

In both of these types, but more especially in the former, the following characteristic syndrome of symptoms is often found in the later stages.

(*a*) The tongue is *dry, fissured, and tremulous;* it is often clean, or there may be a central bar which is coated; it is with difficulty protruded beyond the lips.

(*b*) There is a *fine tremor*, particularly seen in hands, head, and tongue.

(*c*) There are *intermittent tonic spasms* of the muscles of jaws, back of neck, and of limbs.

This bears a superficial resemblance to tetanus, and is at first not uncommonly mistaken for the latter condition. It does not, however, progress, there is never extreme rigidity, swallowing is not unduly interfered with, and there is no opisthotonus. A blood culture in nearly all cases yields a streptococcus.

Progressive emaciation, delirium, and pyæmia complete the picture. The pyæmic abscesses may be found in almost any situation—in joints (*e.g.*, elbow-joint), muscles, and subcutaneous tissue, especially at the sites of intramuscular or hypodermic injections of quinine, saline, etc., as well as in the lungs, pleural cavity, and kidneys. Pulmonary involvement is very common, and is usually the proximate cause of death.

Diagnosis.—This depends upon the blood culture, which, properly performed, seldom fails. In the type which commences suddenly, blood culture is practically always successful. In the type which follows toxæmia, however, repeated blood cultures are sometimes sterile, in spite of the fact that pyæmic manifestations are present. It is probable that the septicæmia in such cases is intermittent, and that the pyæmic abscesses are of the nature of multiple septic infarcts. One such case may be quoted.

Pte. D—— was wounded by H.E. on November 30, 1917. He sustained multiple and serious wounds: (1) Left tibia and fibula were badly comminuted at lower end, and the ankle-joint was involved; (2) right knee-joint was penetrated; (3) right elbow-joint was severely smashed, and was excised at the casualty clearing station. He was admitted to the base hospital on December 3. The wound of the left ankle was badly septic, and amputation was performed a few days later. The knee-joint was septic. The mistake had been made of washing out the joint with saline at the casualty clearing station. The enterococcus was cultivated from the aspirated joint fluid (which contained hæmolysed blood). The excised elbow-joint appeared clean, and was put up on a straight arm-splint. The patient was ill with severe toxæmia; the temperature was remittent

and intermittent, but the pulse was good and the tongue clean. *Blood cultures* on three occasions from December 12 to 27 were sterile. The knee-joint did not do well by the dry method of treatment, and the joint was opened and treated with Carrel's tubes, the limb being put on a Thomas's knee-splint. The pus from the open joint on December 19 yielded the enterococcus, staphylococcus, and *B. perfringens* on culture.

FIG. 48.—Case of streptococcal septicæmia. Note the emaciation.

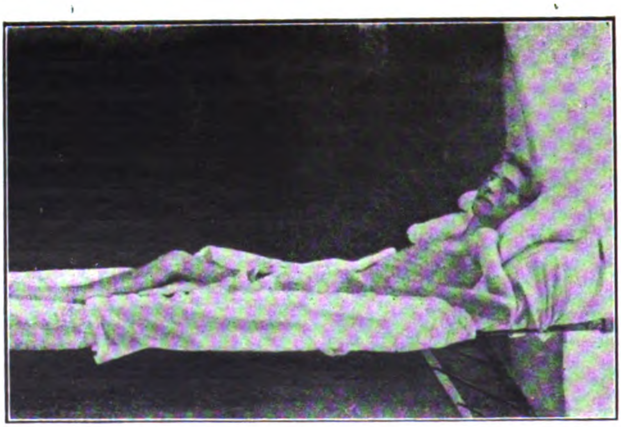


FIG. 49.—Streptococcal septicæmia from knee-joint injury. Note emaciation. See Fig. 50.

The toxæmia gradually became more severe, and ultimately an undoubted septicæmia set in, although the organism could not be obtained by blood culture. A large pyæmic abscess appeared in the gluteal region at the site of an intramuscular injection on January 2, and pulmonary symptoms indicative of septic infarcts appeared about the same time. Pus removed from the pyæmic abscess of the buttock yielded pure *Streptococcus pyogenes*.

A vaccine was made from this organism, but it was too late to have any effect (two days before death), and he died on January 9, 1918. Post mortem the lung showed multiple septic infarcts which had become gangrenous. The right knee-joint showed erosion of articular cartilages on the condyles of the femur.

Prognosis is bad. Out of the above-mentioned fourteen verified cases of streptococcal or mixed streptococcal septicæmia, only three recovered. This gives a death rate of nearly 80 per cent. Most of these cases occurred at an early period, when the rush of the work was too great for septicæmia

FIG. 50.—Same patient as Fig. 49 after amputation and healing of the stump. Note this patient has in addition an extensive wound of the right forearm with a loss of continuity of 3 inches of the radius.

to be investigated, and the possibility of good results from vaccine treatment had not been altogether realised. Of the three recoveries, one recovered after very prolonged administration in large doses of antistreptococcal serum (a photograph showing his extreme state of emaciation is given on the opposite page); one recovered as a direct result of autogenous vaccine treatment; the third was a milder case whose condition yielded very rapidly to vaccine treatment, but who might have recovered spontaneously without it.

One of the cases which ultimately died had a very remarkable reaction to an autogenous vaccine. He was practically moribund when the vaccine

was given, and yet he lived for a month as a direct result of the treatment. In his case advanced tuberculosis of both lungs was a serious complication, which seemed ultimately to turn the balance against him. His case is recorded under "Mixed Septicæmia." The prognosis, therefore, may be regarded as distinctly hopeful, provided that the condition is diagnosed early by blood culture, and autogenous vaccines exhibited. The type in which the onset is sudden and the wounds fairly clean is most amenable to specific treatment. The type which follows severe and prolonged toxæmia is of bad prognosis. The outlook depends here largely upon whether the source of the toxins and organisms in the blood can be cleared away by surgical means, leaving the septicæmia to be treated specifically. This is usually impossible, and these cases are generally hopeless. Lastly, there appear to be rare cases in which the disease runs a very rapid course. We have seen this follow acute streptococcal osteomyelitis complicating compound fracture of the tibia. In these (rare) cases death occurs before the autogenous vaccines can be given. Such cases are hopeless. Where purulent pericarditis supervenes the outlook is bad, unless the condition be diagnosed in time and the pericardium opened.

FIG. 51.—Case of streptococcal septicæmia.

A case of a man who ran a nail into the sole of his foot and got a most virulent streptococcal septicæmia. Red lines up to the groin, and thrombosis of all the superficial veins of the limb up to the knee. Temperature 104° F.; delirious; cardiac murmurs. The vein was tied high up in the thigh, the soft parts round the ankle slit up, and a vaccine made, within fifteen hours. His temperature dropped to normal, and he made an uninterrupted convalescence. The photograph shows the operation wound at the ankle, and a large slough down to the muscle, owing to a streptococcal thrombosis of the saphena vein and its branches.

Treatment.—The treatment is prophylactic and specific.

PROPHYLACTIC TREATMENT is the most important, and consists of the whole antiseptic treatment of wounds. The prevention of streptococcal septicæmia will be accomplished in proportion to the thoroughness of surgical technique in complete excision of wounds, complete immobilisation

of fractures and joints, and complete sterilisation of wounds by thorough attention to the details of the Carrel-Dakin or other efficient antiseptic treatment.

In particular the prevention of knee-joint sepsis by the newer methods of treatment of penetrating wounds of the joint is responsible for saving a large number of cases from streptococcal septicæmia.

There is, however, a small residue of cases which arises even when the above prophylactic treatment has been as far as possible carried out. There remains for these established cases of septicæmia specific treatment in the form of sensitised autogenous vaccines.

Specific Treatment : Sensitised Autogenous Vaccines.—The success of specific vaccine treatment depends largely upon an early diagnosis by blood culture, and the consequent early institution of the treatment. The only way to secure this is to make a blood cultivation from all cases which have an unexplained swinging temperature for two or three days. It is inadvisable to wait until the typical tetanoid spasms, tremor, and tongue are seen, for by that time it is probable that the lung has become involved, and, in addition, the patient's powers of resistance, on which the vaccine treatment depends, have become much weakened. If a streptococcus be found in the blood, the autogenous vaccine should be ready within three days at the most, and within forty-eight hours if particular speed be required (the test of the vaccine for sterility being then omitted). The dose of vaccine given should be large—say ¼ to ½ of a slope (= 500 to 1,000 million of organisms) as the commencing dose ; 20 to 40 c.c. of stock polyvalent antistreptococcal serum should be given intramuscularly just before injection of the vaccine, in order to sensitise it. The dose should be doubled or otherwise increased according to the local reaction produced. The succeeding doses should be given when the local reaction has just subsided—*e.g.*, every third or fourth day. Should pyæmic abscesses arise, the causal organism or organisms should be cultivated as far as possible from the pus, and they should be incorporated, along with the original organism from the blood, in a fresh vaccine.

The results of sensitised autogenous vaccine treatment in streptococcal septicæmia of the lasting type with the sudden onset are often very striking, especially if it be exhibited early. A brief description of the one case may serve to illustrate this point.

Sergeant L——, 11th Scottish Rifles, was wounded on May 8, 1917, by H.E. He sustained a very severe compound fracture of the head of the tibia and external condyle of the femur, the knee-joint being involved. On admission to the base hospital on May 11 the wound was offensive and gangrenous, and foul gas exuded from it. Carrel tubes were inserted into the joint. On May 27 he had a severe secondary hæmorrhage from the popliteal artery, and amputation was performed in the middle third of the thigh, and the flaps left open. After this his evening temperature fell gradually to a degree or so above normal, until June 6, when it

rose suddenly to 104° F. and remained continuous, with high evening exacerbations. The amputation stump was clean. A blood culture was therefore performed on June 10, and it yielded typical *Streptococcus pyogenes*. On June 13 he had 10 c.c. antistreptococcal serum, and $\frac{1}{10}$ slope streptococcus autogenous vaccine. By this time the tongue was dry and tremulous, the hands and head showed typical tremor, but tetanoid spasms had not yet appeared; the pulse was rapid and weakening, the temperature was high, and the patient was very ill. The local reaction to the vaccine was very slight, and undoubtedly the dose was too small. The general condition of the patient was, if anything, improved; certainly he was no worse. On June 16 he had ½ slope sensitised vaccine, and next day his condition had greatly improved. His tongue was moist, his pulse was improved, and he felt much better. On June 19 and 22, 1 slope of sensitised vaccine was given, and from June 23 his temperature gradually fell to normal, the tremor disappeared, and the facies, previously drawn and anxious, became again healthy. The patient now looked and felt well. On July 1 the temperature began to rise again a little in the evenings, and a cough appeared. Dulness and râles could be made out in the left lower lobe behind, and the patient was coughing up pus by July 3. The original vaccine was continued for some time, with good results. The general disturbance produced by the abscess of the lung was remarkably small and he felt fairly well. His only discomfort was his cough and sputum. The sputum was almost pure pus, and at times he expectorated 2 to 3 fluid ounces of it, almost all at once. After such a bout of coughing he was relieved for a day or two. On several occasions, while coughing up and expectorating these huge amounts of pus, he almost died from suffocation. On July 3 a vaccine made from his sputum and containing ½ slope pneumococcus, $\frac{1}{14}$ slope pneumobacillus, $\frac{1}{20}$ slope *M. catarrhalis*, in 1 c.c., was incorporated with his original vaccine. The result was excellent. After two doses the cough and sputum were reduced to almost negligible proportions and his general condition rapidly improved. The cough and sputum remained in this modified form for two or three weeks, and then gradually disappeared. His amputation stump was secondarily sutured on September 25, and healed by primary union. The patient was evacuated to hospital ship well and able to look after himself on October 28, 1917.

In this case, although progress was somewhat slow, everything went to show that the autogenous vaccines saved the man's life.

2. Coliform Type

This is a somewhat rare but interesting type of septicæmia or bacillæmia complicating wounds. In a series of nearly 2,000 cases of gunshot wounds, five cases of this condition were discovered. As it is a relatively mild condition, it is possible that some cases have been missed.

B. Coli Communis.—In one of the cases typical *B. coli* was isolated. A brief account of this case may be given.

Pte. C——, R.A.M.C., was wounded by H.E. on May 8, 1917. He sustained a severe compound fracture of the upper extremity of tibia and fibula. He was admitted to the base hospital on May 9, and the wound was treated with Carrel tubes and eusol. On May 17 the knee-joint was distended and painful, and a secondary hæmorrhage from the tibial vessels occurred. The limb was amputated through the lower third of the femur, when it was seen that the joint had become infected through the superior tibio-fibular articulation. On May 23 secondary hæmorrhage again occurred, this time from the femoral artery in the stump. The artery was religatured, higher up. On May 26, the artery gave way again, and secondary hæmorrhage occurred for the third time. This time the artery was ligatured in Hunter's canal, but death occurred two hours later.

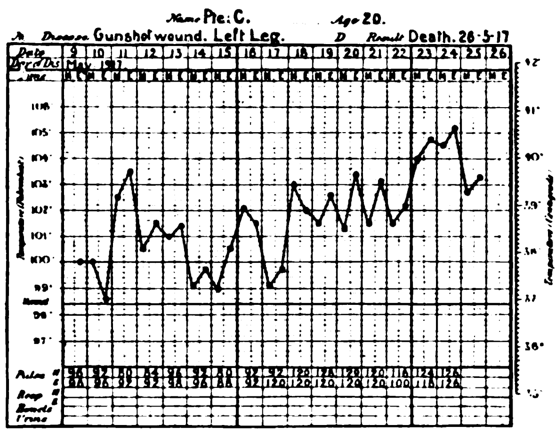


FIG. 52.—Septicæmia due to *B. coli communis*.
Death from secondary hæmorrhage.

The temperature had been running from 99° to 100° F. until May 18, when it suddenly rose to 104°, and remained high and remittent (101° to 104°) until death on May 26. A blood culture performed on May 22 yielded typical *B. coli*. Apart from the high remittent pyrexia and severe general illness, there were no typical or characteristic symptoms.

In this case the temperature chart, general appearance, and blood culture, suggested that a *B. coli* septicæmia was present during the eight days preceding his death. It is impossible to say what the course of the disease would have been had not the third hæmorrhage terminated his life, but the appearances suggested that this particular form of septicæmia, a *B. coli* bacillæmia, is a severe one, and one that would lend itself to specific treatment by autogenous vaccines. The correlation of this septicæmia with severe compound fractures, and also with severe and repeated secondary hæmorrhage, are probably points of some significance.

Coliform Bacilli: *General Features*.—The other four cases of coliform septicæmia formed a single clinical group. Three were associated with

compound fractures and one with a gunshot wound of the abdomen. The average length of time between date of wound and onset of the septicæmia was twenty-one days. The period of pyrexia due to the bacillæmia was in two cases separated from the pyrexia due to the wound sepsis by an interval of apyrexia ; in the other two cases the temperature never reached the normal line until the bacillæmia had disappeared, but the pyrexia due to the bacillæmia was clearly demarcated on the chart by the increased height of the temperature and the depth of the remissions. *In all four cases the disease ran a typical course of seven to nine days' intermittent pyrexia.* The chart from the G.S.W. abdomen case is appended to illustrate the type of fever produced.

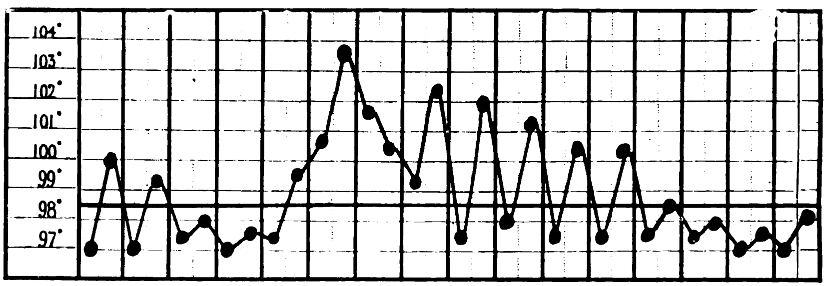


FIG. 53.—Case of coliform septicæmia.

Symptoms.—The symptoms were not characteristic. They were the general ones of moderately severe fever. The condition resembled in general features paratyphoid fever, but there was no eruption nor any of the peculiar features of that disease present. Repeated Widal tests for the enterica group were quite negative, as were also the examinations of fæces. The urine was not tested. After a period of seven to nine days' intermittent and remittent fever, during which the patient was sharply ill, the symptoms subsided and convalescence was rapid.

Causal Organisms.—A coliform bacillus was isolated from all four of these cases by blood culture on the third or fourth day of the disease. In three of the cases the organisms isolated bore a striking similarity, and their reactions did not enable them to be identified as any known or described organisms of the coli-typhoid group. They were Gram-negative, non-motile bacilli, growing readily on agar and on bile-salt agar. They produced acid in glucose media, but not in lactose, mannite, saccharose, nor dulcite. Two of the strains acidified litmus milk, and one clotted milk in addition. Although these carbohydrate reactions resemble those of *B. dysenteriæ* (Shiga), the growth on agar was different from that of the dysentery bacillus, nor did agglutination by high-potency anti-Shiga serum occur.

The fourth organism gave reactions similar to those of *B. coli anaerogenes*.

Allied Bacillæmia.—The above form of septicæmia is particularly interesting in that it resembles an infection which not uncommonly occurs during convalescence from acute bacillary dysentery. The pyrexia in the latter cases is of about the same duration (seven to nine days), and the clinical appearances resemble those mentioned above very closely. About a dozen of such cases have been seen by the authors and verified by blood cultures, the organisms obtained being in most cases *B. coli*, but in several cases coliform bacilli of various kinds.

Treatment.—In all the cases noted, except that due to typical *B. coli*, the condition has subsided uneventfully under ordinary general treatment. No specific treatment has been so far called for, but in case of a more severe or dangerous illness of this type we would not hesitate to employ autogenous vaccines.

The case in which coliform septicæmia complicates a gunshot wound of the abdomen is quoted as an example:

Pte. B——, 2/20th London Regiment, was wounded on April 24, 1917, in the right leg, right upper arm, and in the abdomen. All the wounds were excised at the casualty clearing station and Carrel's tubes applied to the wounds in the limbs. The abdominal wound was perforating, the wound of entry being over the ascending colon, and the wound of exit in the left lumbar region. The abdomen was opened at the casualty clearing station, and a hole in the descending colon was sutured.

On admission to the base hospital on May 2, there was a fæcal fistula in connection with the abdominal wound of entry. The other wounds were clean. The temperature settled to normal on May 6, and remained so until May 15. From May 15 to 22 the pyrexia shown on the chart (Fig. 53) occurred. On May 18 a blood culture was performed, and yielded a coliform bacillus. The subsequent progress was uneventful. The fistula was closed on May 30 and the other wounds were sutured. On June 29 he was evacuated to hospital ship.

3. Gas-Gangrene Type (Pyæmic or Metastatic Gas Gangrene)

This type of pyæmia has been described by various observers during this war. Cuthbert Wallace has mentioned two cases in which metastatic lesions were manifest shortly before death, and two similar cases are recorded by Kenneth Taylor. Mullally and McNee describe a remarkable case in which the bacillus of malignant œdema, circulating in the blood, became localised at the sites of injections of antitetanic serum and pituitrin. Hartley has described five cases of metastatic gas gangrene, with recovery in three.

We have met with five cases of this metastatic gas-gangrene pyæmia. These were all so rapidly fatal that blood culture could not be performed during life, but *B. perfringens* was recovered from the heart's blood in all cases at the post-mortem examination, which was always held a very few

hours after death. In four of the cases the condition was a complication of gunshot wounds with compound fractures or lung injury ; in one case the gas gangrene supervened on an accidental fracture of the tibia and fibula. This case is described under "Complications of Gas Gangrene" (*q.v.*). In all these cases gas gangrene was present in the original wound.

The metastases, except in the cases in which they occurred in the lung, were localised to sites of pressure, two being in the muscles of the buttock and one in those of the scapular region and posterior triangle of the neck. The muscles in the area of the metastases were brick-red where the process was commencing and greyish where it was more advanced, were crepitant, and exuded thin sanious fluid and bubbles of gas with a peculiar heavy odour. Where the process was advanced there was discoloration and bullæ-formation in the overlying skin. The muscle fluid and the fluid in the bullæ in all cases contained *B. perfringens* in large numbers.

The prognosis is bad. In all our cases death occurred within two or three hours of the metastatic condition being observed. Hartley has described three cases in which the spread of the condition was much less rapid than this, and in which recovery followed early excision of the gangrenous part of the muscles in the metastasis.

For further remarks on this condition, with description of cases, the reader is referred to the previous chapter on "Gas Gangrene," and to the following section on "Mixed Type."

4. Mixed Type

On rare occasions more than one organism may be found in the blood-stream, giving rise to septicæmic symptoms, more especially at an advanced stage, when death is imminent. In such double general infection the offending organisms may be either aerobes only or a combination of aerobe and anaerobe.

We have met with three cases of this condition, of which two were found to have a streptococcus and a coliform bacillus in their blood, and the third to have a streptococcus and *B. perfringens*. All three cases presented typical symptoms of streptococcal septicæmia, and clinically there was little, if anything, to indicate a double hæmic infection.

(*a*) **Streptococcus and Coliform Bacillus.**—Both cases presented a typical clinical picture of streptococcal septicæmia of the type with the sudden onset, which has been described above. One example may be quoted. The tetanoid spasms were not present in this case, but were typically present in the other.

Pte. L——, 2/21st London Regiment, was wounded by shrapnel on the left side of the back on April 7, 1917. The wound was a long burrowing one, which terminated in a compound fracture of the tenth rib. The wound was excised and treated with Carrel's tubes and eusol. The temperature had settled to normal by April 1, and remained so until April 19,

when it rose suddenly to 103° F., and remained high and remittent till death on May 16. The septicæmia lasted twenty-seven days. He had frequent rigors; the tongue became dry, fissured, and tremulous; pulse was at first slow and full, and later on rapid and weak. The typical tremor, delirium, progressive weakness and emaciation were present. Eight days before death signs of a pyæmic abscess in the left lung appeared, and four days before death the right lung also became involved. A blood culture on May 2 yielded typical *Streptococcus pyogenes*, along with a coli-form bacillus, whose salient characters were as follows: A small Gram-negative, non-motile bacillus, growing profusely on agar, and in pale colonies on McConkey agar. It produced no fermentation of lactose, glucose, mannite, dulcite, or saccharose, but clotted milk; it liquefied gelatine and produced indol in peptone-water media. This case was treated with antistreptococcal serum without result; autogenous vaccines had not been tried at this period.

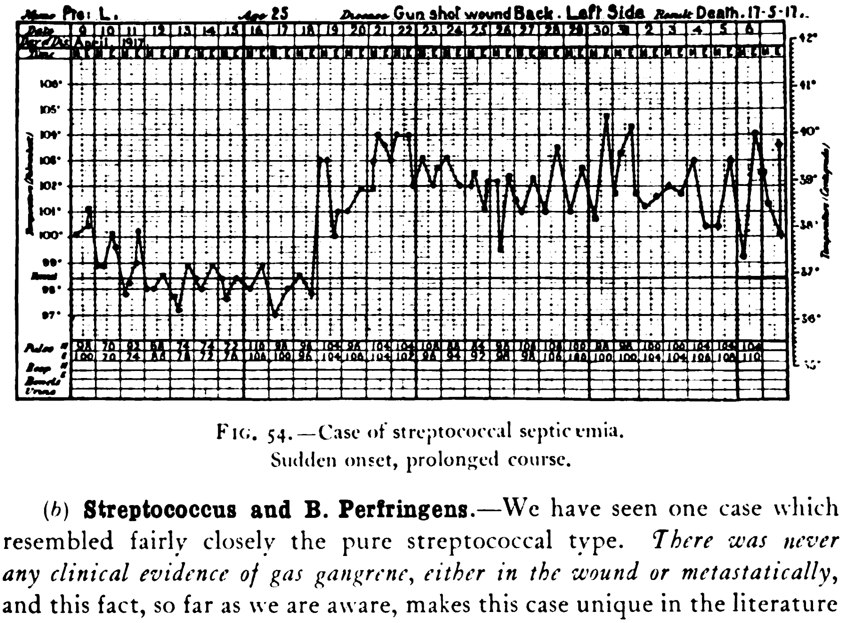


FIG. 54.—Case of streptococcal septicæmia.
Sudden onset, prolonged course.

(*b*) **Streptococcus and B. Perfringens.**—We have seen one case which resembled fairly closely the pure streptococcal type. *There was never any clinical evidence of gas gangrene, either in the wound or metastatically,* and this fact, so far as we are aware, makes this case unique in the literature of the gas bacilli. It is, of course, common for the *B. perfringens* to be isolated from wounds which show no clinical signs of gangrene, but rarely, if ever, has the corresponding condition in the blood-stream been described. That *B. perfringens* was in the blood for a considerable time without producing any gaseous manifestations of its presence was clearly shown, for it was cultured from the blood during life on two occasions, at an interval of seventeen days, and was cultured also from the heart's blood post mortem. All these cultures yielded the typical reaction of the perfringens group in a milk-culture medium, and pure anaerobic cultures of the organisms on agar were obtained.

In gas-gangrene pyæmia or metastatic gas gangrene, which is now a well-recognised clinical entity, the gas bacillus must reach the site of the metastases in most cases by the blood-stream. Not uncommonly the metastatic lesions in such cases are situated on the opposite side of the body from the primary lesion—*e.g.*, in the buttock of the opposite side. In no case, however, has gas been noted within the bloodvessels during life and one must conclude that the organism cannot undergo multiplication to any appreciable extent in the blood-stream. The case described below of mixed septicæmia, whether it be regarded as a primary true gas-gangrene septicæmia (without pyæmia) or as a primary streptococcal septicæmia (both organisms having been present in the blood), leads also to the same conclusion that gas bacilli may be present in the circulating blood without producing visible gaseous signs of its presence. The reader is referred to the chapter on the "Bacteria of Wounds" (p. 69), where it is shown that *B. perfringens* has no power of growth in fresh normal serum. This fact suggests as an explanation of the phenomenon that some property possessed by the serum during life is an inhibiting influence on the growth and multiplication of the organism in the blood-stream. The relative frequency of its presence in the circulating blood without pyæmic manifestations could only be determined by careful systematic blood cultivations from a large series of cases. The presence of metastases may be determined by pressure, by local devitalisation of various kinds, such as that produced by gas-gangrene toxæmia from a primary gangrenous lesion, or by other obscure factors. One or more of such factors may then supply the lacking condition for the multiplication of the organism, and set up that "explosive growth" which is so characteristic of its activity.

The following case is also of interest in that it shows the remarkable effect which may be produced by autogenous vaccines in cases of septicæmia in which the streptococcus is a causal organism.

Pte. D—— was wounded in May, 1917, by H.E. He sustained a severe wound of the right shoulder, with compound fracture of the acromion process and spine of the scapula, compound fracture of the upper extremity of the humerus, and penetration of the shoulder-joint. The wound was excised as far as possible and treated with Carrel's tubes and eusol. In June symptoms of septicæmia arose. Temperature became high and remittent; pulse soft and rapid; tongue, at first moist, later became dry and tremulous; complexion very sallow; the tremor appeared at a later stage of the disease; tetanoid spasms did not occur. Ten c.c. of the blood were withdrawn for culture on June 16, and were distributed, according to the usual procedure, between one tube of milk and two of broth. After incubation anaerobically for twenty-four hours, the milk-culture tube was found to show the typical stormy fermentation associated with the perfringens group. After several anaerobic subcultures from this tube, a pure culture of *B. perfringens* was obtained on agar. The broth tubes yielded no growth.

A week later the septicæmic symptoms began to resemble more closely

those of the streptococcal type. The tongue became dry, with a central furred zone, and the tremor appeared. The patient was by this time extremely ill. Since the symptoms suggested streptococcal septicæmia, and the streptococcus had not been found in the blood, a catheter specimen of the urine was cultured, and it yielded a pure and abundant growth of a long-chained streptococcus which grew in minute colonies on trypagar. A vaccine made from this organism was injected on June 26, in a dose of ¼ slope, preceded by 10 c.c. antistreptococcal serum. The patient on this day appeared moribund, and one of us had great difficulty in persuading the medical officer in charge of the case that the vaccine should be tried on a patient who was obviously *in extremis*. The patient looked and felt better the next day, and although a day or two previously he had virtually abandoned the struggle and made all preparations for death, he now said firmly that he was not going to die after all. On June 29 the improvement had still continued; the tongue was moist again for the first time since about June 20, and the tremor had almost gone. He was eating and sleeping well. The temperature, however, did not become normal, although it fell a degree or two. A second injection of the sensitised vaccine on June 29 was followed also by good results. On July 2 he had reached the zenith of his improvement. By July 5 he had again become weak; the tongue was dry; his wound was very foul, with pus pocketing in various directions. He was too ill to stand the operation of amputation of the arm complete with scapula, which would have been the only way of removing his septic wound.

On July 3 blood was again withdrawn for culture, and on this occasion the milk and a broth tube were incubated anaerobically. *B. perfringens* was again cultivated from these tubes, and, in addition, both tubes yielded *Streptococcus pyogenes*. On July 6 a combined sensitised vaccine was injected, containing both strains of streptococci, that isolated from the blood and that from the urine. This was followed by a second transitory period of improvement on July 7, 8, and 9. After this, in spite of all treatment, he went steadily downhill, and died on July 23—*i.e.*, twenty-seven days after the first injection of vaccine had been given, when he appeared to be in a moribund condition.

Post-Mortem Notes.—The body was emaciated to an extreme degree.

Lungs.—The whole of the right lung was collapsed and full of tuberculous nodules, both caseating and cicatrised. Many of the lesions were active. The whole of the right pleural cavity was obliterated by adhesions, and the pleuræ were greatly thickened.

Similar tuberculous lesions were scattered through the substances of the upper lobe of the left lung, and the apex was very adherent.

The bronchial, mediastinal, and mesenteric glands were enlarged; some were caseated and others calcareous.

All the organs of the body were extremely atrophic. The blood contained no gas. From the heart's blood there was obtained by culture *B. perfringens* and a streptococcus.

CHAPTER XI

EFFECTS OF CLIMATE AND CERTAIN DISEASES ON WOUNDS, WITH DIAGNOSIS AND TREATMENT

By Lieut.-Colonel L. F. Smith, C.M.G., R.A.M.C.

These remarks apply to the Salonika army.

Climate.—The effects of climate *per se* on wounds and as a predisposing cause of their infection have been frequently discussed. Climate itself would appear to have little effect on wounds, except in delaying union, and thus acting as a predisposing cause of infection. This delay in union was not often seen in the cases alluded to in other chapters, but in hotter and damper climates it is a real menace. In Aden especially it has been noticed that clean operation wounds do not rapidly heal. They exhibit a want of tone, and sometimes remain patent for a considerable period.

In Salonika, where delay in union of wounds from climatic causes alone occurred but rarely, conditions vary much during the different seasons. In the winter-time frequent cold spells alternate with warm spring weather, whilst in the summer moderate heat, about 100° F., prevails, with occasional thunderstorms. At all times, except during and after rain, dust is abundant. This is a real menace and a possible potent factor in infection. For two or three days together, when the north wind, called the "Vardar wind," was blowing, it was impossible to operate upon or even to dress cases. When dressings were taken down after the wind had subsided, the advantages of the Carrel-Dakin scheme of treatment were apparent; although the dressings were in many cases impregnated with dust, which dust, to a large extent, was composed of dry horse-dung, the continuous sterilisation had been going on, and no evil effects on the wound were noticed.

Beyond what has been said, climate and climatic conditions *per se* do not appear to further influence the progress of wounds.

Diseases Peculiar to the Country.—There is not the slightest doubt that diseases associated with climate or geographical situation do markedly influence the progress of a wound.

The chief diseases met with in Salonika are malaria and dysentery.

Malaria.—Malaria, as is usual, is divided into three types—benign and malignant tertian, and quartan. The latter may be disregarded, as out of 13,000 cases only a few scattered cases were seen, and from the surgeon's

standpoint not much difference is to be noted between the two tertian forms.

It may be mentioned that in a long tropical experience, including in its scope various parts of India, Arabia, and West Africa, no malaria of equal severity to that obtaining in Salonika had been previously seen by the writer of this chapter. The rapidity with which serious and even fatal symptoms, especially of the cerebral type, came on, even in newcomers to the country; the extraordinary virulence of the attack, as shown by profound anæmia and cardiac symptoms, in the form of persistent tachycardia with liability to faints, are quite rare in cases of malaria as met with in other parts of the world or as described in books.

As the fall of the Grecian Empire has by some been attributed to the advent of malaria introduced from the East, the explanation may lie, not in the introduction of the disease, but in the pernicious type that was introduced.

It was admitted by practically everybody that most wounded men on this front had suffered from malaria or were malarial carriers, even where there was no previous history of a definite attack, or at any rate an attack of such severity as to necessitate "reporting sick." It will thus be seen that the disease, even though latent, must inevitably play a large part in complicating wounds and their treatment.

Effects of Malaria complicating Wounds.—The effect of malaria on wounds may be (*a*) general, (*b*) local, or both.

A. **General Effect.**—It has been noticed that the mere infliction of a wound, whether it be received in action or in the operating-theatre, is sufficient to precipitate an attack of malaria, not only in those who have had one or more previous attacks, but also in those who had not consciously suffered from the disease before.

This attack may be either of the usual sharp variety, characterised by the cardinal signs of shivering followed by sweating, headache, and sudden rise of temperature, or the more insidious type of cerebral malaria, with head symptoms coming on slowly and gradually, or coma coming on at once.

In the first or ordinary type no great difficulty is experienced by those who have any knowledge of the disease in diagnosing and treating the case. A blood-film should be taken and examined as early as possible, and the usual treatment carried out.

The blood-film determines the type and shows as to whether the rise of temperature and the concomitant illness is due to sepsis or not; but even if the film, as sometimes happens, is negative, this does not exclude malaria, and antimalarial treatment should be energetically carried out. Quinine properly administered will act as a diagnostic as well as treatment.

It is the cerebral type which is difficult to diagnose accurately and to treat always with success. A man is brought into hospital suffering from a very severe gunshot injury, such as an extensive compound comminuted

fracture of the femur or a compound depressed fracture of the skull. He is dealt with on ordinary surgical lines, and appears to be doing well. On the same evening or the next day he goes off his head, becomes delirious, talks nonsense, gets drowsy, or even gets delusions of persecution with suicidal tendencies, as occurred in one case who attempted self-destruction by cutting his throat. The temperature may run up to 105° or 106°, or, on the other hand, may keep at a lower level, not rising above 101° or 102°.

To one without experience it may easily happen that the whole of this train of symptoms may be put down to the injury, and consequently the disease remains untreated. The principle adopted in the hospital in which these wounds were dealt with was to take it for granted that all these cases were suffering from malaria, and to treat them as such in addition to their wounds. If cerebral symptoms appeared, they were more energetically treated. To show the difficulty that may be experienced we may quote one case :

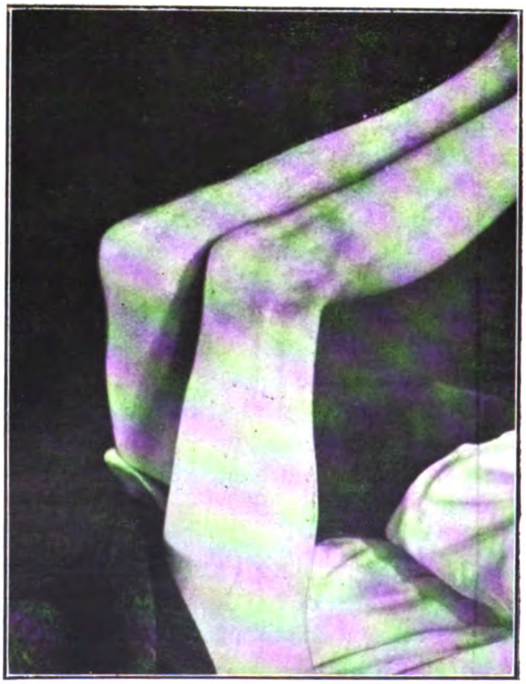


FIG. 55.—Kernig's sign present in a case of cerebral malaria.

Pte. —— was admitted to hospital with a severe fracture of his right femur on October 12, 1917. In addition he had sustained abrasions of the scalp and other parts of his body. He had not been given antitetanic serum up the line. The fracture was dealt with under an anæsthetic. The same evening he complained of difficulty in swallowing and opening his mouth, and he passed a very restless night. On admission he was given

1,000 units of antitetanic serum. On the next day he still had some difficulty in swallowing, with stiffness and rigidity in the muscles of the back of the neck. He was given a further dose of 1,000 units of antitetanic serum. His temperature at this period was between 102° and 103°. Towards evening the temperature was 102°; the stiffness in the neck muscles was still present. Kernig's sign was present; he vomited and became drowsy. Cerebro-spinal meningitis was thought to be a likely solution of his case. A lumbar puncture was performed, and though the fluid was under tension, yet it was clear and bacteriologically negative in every way to this condition. A blood-film proved negative to malaria. He was given 40 grains of quinine intramuscularly.

On the following day he was still comatose, totally incontinent of both fæces and urine, looking blue about the lips and ashen about the face. Tachycardia was very pronounced.

He was given 50 grains of quinine intramuscularly. His temperature was 102°, he was still very drowsy and incontinent, and the cardiac condition had not changed. Towards evening he started to improve, the tongue was cleaner, and he was more rational. Since this time, and it is now the ninth day since the onset, he has made satisfactory progress. He is quite rational, taking food well, tongue clean, no incontinence by day, though he has still nocturnal enuresis, temperature 99°, and there is tachycardia. He is still receiving 20 grains of quinine intramuscularly each day.

This was an undoubted case of severe cerebral malaria, and is interesting in that it shows the difficulty for those who have had little experience of the disease in making an early and correct diagnosis.

There is little doubt that this severe attack was precipitated by the injury and its necessary surgical treatment. The case is also interesting in that it shows, as I have seen in other instances of cerebral malaria, rigidity of the muscles of the back of the neck, headache, drowsiness, vomiting, and the presence of Kernig's sign. Thus, the syndrome of cerebro-spinal meningitis can be closely imitated by cerebral malaria.

Control of the sphincters may be completely lost with dual incontinence, and this incontinence, as improvement proceeds under treatment for the malarial condition, improves during the daytime, but persists while the patient sleeps. This complication appears to be difficult of treatment, besides being a very potent source of infection to open wounds.

Treatment.—The treatment of malaria consists in the exhibition of quinine after well emptying the bowels with calomel, followed by magnesium sulphate and an enema if necessary.

Latterly it has been strongly urged by workers, whose experience of the disease lay chiefly in England, that it is immaterial whether quinine is given by the mouth, intramuscularly, or intravenously. This is quite contrary to our experience both in Greece and elsewhere. For benign and malignant tertian of the ordinary mild type quinine by the mouth

will suffice, especially if not less than 45 grains are given daily until the patient is well under the influence of the drug; but if there is vomiting, a dirty coated tongue, or gastritis, quinine by mouth is useless, because the patient cannot absorb it. Intramuscular or, if necessary, intravenous administration of the drug must be carried out for all such cases and for all cases of the cerebral type.

And no small doses will suffice. Twenty grains intramuscularly twice a day, as a rule, is enough, but if no improvement is shown or drowsiness continues, larger and what would be called heroic doses must be tried.

One case in particular with severe anæmia and marked coma was given 20 grains intramuscularly, followed in two hours by 20 grains intravenously, followed later in six hours' time by 20 intramuscularly. On the following day two intramuscular injections, each of 20 grains, were administered before any definite improvement took place.

Objections to Intramuscular Administration of Quinine.—The chief objection to the administration of quinine intramuscularly is the risk of abscess-formation at and around the site of injection. Such an occurrence can only be due to want of care and knowledge of technique.

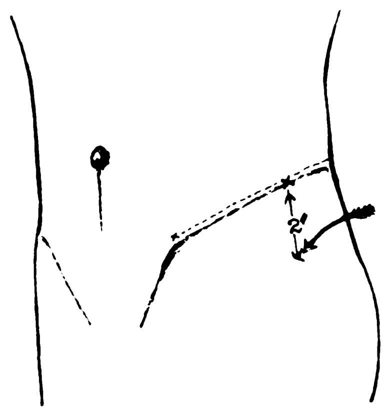


FIG. 56.—Site for intramuscular administration of quinine.

Method of Intramuscular Administration and the Technique.—After thoroughly preparing the skin and painting with iodine, the needle of the syringe is entered at a point in the skin 2 inches below the mid-point of the iliac crest. The needle should be about 1½ inches long, and it should be entered perpendicularly to the skin. Quinine bihydrochloride sterilised in normal saline solution in the proportion of 1 to 2 is now injected up to the required amount, 10, 20, or 30 grains being given.

In rare instances, where after several injections the buttocks are sore and painful, the arm may be selected, the deltoid being the best and most convenient muscle. Unless absolutely contra-indicated, we would always recommend the buttock as the best and safest site for intramuscular ad-

ministration, for accidents have happened when the arm has been selected, a number of cases of musculo-spiral paresis having resulted.

The medical officer giving an intramuscular dose of quinine must be sure that his solution of quinine is sterile and reliable ; that his hands, the patient's skin, and the syringe are sterile ; and that he injects the solution into muscle and not into subcutaneous tissues.

Intravenous Administration of Quinine.—This is called for chiefly in the treatment of the severe types of cerebral malaria. The all-important question seems to be, how much fluid can a severe case of cerebral malaria tolerate ? Owing to the existing degenerate state of the myocardium in these bad cases, the heart can stand very little extra strain, and very rapidly gives out, death following as the result of paralytic distension. One case may be quoted to illustrate this :

Pte. ——, who had just got over the worst part of an attack of malaria, was feeling fairly well and sitting up. He made a sudden effort to kill a fly on his bed with an ordinary fly-flapper. Before the act of killing the fly was completed, he fell back dead. A post-mortem examination revealed an acutely dilated right heart with advanced degeneration of the myocardium.

There is at present in hospital a case of a patient who, while undergoing treatment for a fractured femur, suddenly developed cerebral malaria, and became comatose. With energetic treatment he has got over the worst part of the attack, but on the slightest exertion he suffers from tachycardia, the pulse-rate going up to 120 or more. This makes attention to his wounds a very difficult and anxious procedure.

In a few cases death has occurred either during or immediately following the intravenous administration of quinine ; consequently this method of giving the drug was open to criticism, and at the time condemned by certain observers.

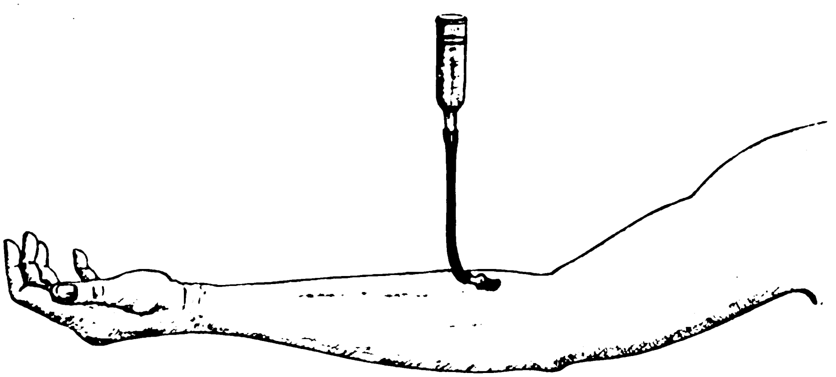


FIG. 57.—Intravenous administration of quinine.

At this particular period the amount of normal saline solution introduced with the drug was considerable, and it is quite conceivable that its

introduction into the circulation was more than the heart could then deal with. Profiting by experience, we now give with the drug an amount of saline which has been reduced to a minimum. Not less than 8 ounces and not more than 12 appear, after considerable experience, to be the limits of safety.

The skin covering the vein selected is thoroughly cleaned and disinfected with iodine. The medical officer, after thoroughly washing his hands, proceeds to introduce the sterilised needle into the vein. When once the needle is in the vein, the dose of quinine bihydrochloride in the 8 or 10 ounces of warm normal saline solution is *very slowly* run into the circulation. The process should be carried out *very slowly indeed*, so that no undue strain is at any time put upon the degenerate heart muscle.

A case may be quoted to show what dose of quinine may be given in the twenty-four hours, if necessary :

Pte. —— was admitted to hospital suffering from malaria. Despite quinine given in 30 grain doses by mouth (two doses of 15 grains daily), he suddenly became comatose within forty-eight hours of admission. He was given, during the next twenty-four hours, 60 grains of quinine intravenously and 60 grains intramuscularly—that is, 120 grains. He rapidly regained consciousness within the next twelve hours, and when seen at the end of this period he had tachycardia and a considerable degree of jaundice. He was, however, able to take fluid nourishment, and to retain it. During the following twenty-four hours he was given a further 180 grains of quinine, both intramuscularly and intravenously. The change in his condition in forty-eight hours was magical. From deep coma he became conscious and rational, taking food well and reading the daily paper. This is only one example from a number of similar cases.

Treatment of Severe Malarial Anæmia.—Some of the severest types of anæmia may follow malaria, and clinically these resemble pernicious anæmia. They differ, however, in that the colour index is below unity, though normoblasts and other atypical blood cells are present.

These cases are particularly severe and serious. Vomiting, with blood in the vomit, and diarrhœa are two serious complications of malaria, besides total disinclination for food and inability to digest it when taken. These cases respond badly to quinine and the best results have been obtained by direct transfusion of blood from a healthy donor.

Direct Transfusion of Blood.—The two methods that have been used in performing this operation are as follows:

A. *By Multiple Syringes.*—The donor is seated in a chair. After carefully cleaning the skin, the needle of a 10 c.c. glass syringe is introduced into the vein. The syringe is filled with blood, detached from the needle, which is left in the vein, and handed to another medical officer, who immediately empties it into the vein of the recipient. While this is taking place, another syringe full of blood is extracted from the donor and again passed on to the recipient ; periodically the needle in the vein of the recipient is

flushed with 10 c.c. of normal saline. During this process eight or ten syringes, all of equal size and pattern, may be in use.

When the desired quantity of blood has been transfused from donor to recipient, the needles are removed from the vein of both and a dressing applied.

The advantages this method possesses is that by its adoption it can be accurately gauged how much blood the recipient has acquired from the donor.

B. *By Cannulæ and Tube.*—This method, though less accurate, has given good results. Two glass cannulæ are connected by means of a piece of rubber tubing. The whole apparatus is boiled, and then immersed

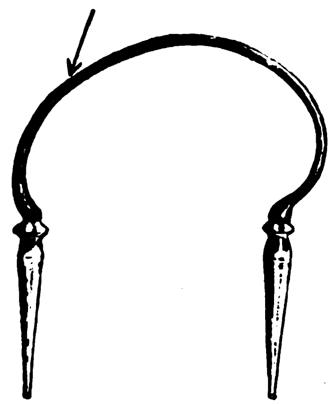


FIG. 58.—Apparatus for direct transfusion of blood.
Arrow shows position and direction for insertion of needle and introduction of normal saline, if necessary, during the operation.

in sterile medicinal paraffin. The median basilic vein is exposed in both donor and recipient, who lie in bed side by side, the feet of one being directed towards the head of the other. The two arms are now placed side by side, the hand of one man being directed towards the axilla of the

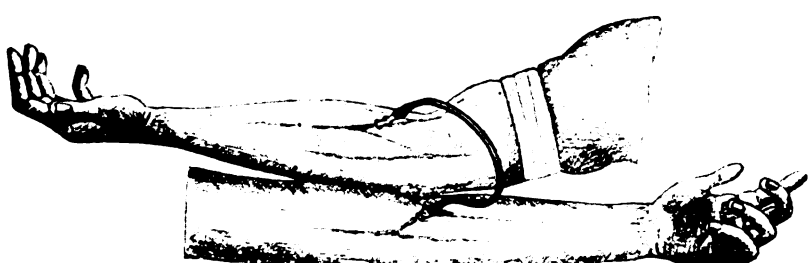


FIG. 59.—Direct transfusion of blood : apparatus applied.

other. The cannulæ with the connecting rubber tube are now removed from the paraffin and filled with normal saline. The cannula introduced into the vein of the donor should have its apex directed towards the hand,

and the vein should be ligatured above the opening made in it for the introduction of the cannula. The cannula in the vein of the recipient should have its apex directed towards the axilla, and the vein should be ligatured below the opening. A Martin's rubber bandage is now wrapped around the upper arm of the donor, not tight enough to stop the arterial flow, but sufficiently tight to interfere with the venous return. This gives a greater venous pressure in the arm of the donor than in that of the recipient, and consequently a direct flow of blood is established. To make sure the blood is running, the needle of a 10 c.c. syringe is periodically introduced into the rubber tubing, and after pinching the latter 10 c.c. of saline are introduced into the vein of the recipient. This clears the glass cannula, and on releasing the rubber tubing it will be seen if the blood still continues to flow. The process should be stopped immediately on any sign of faintness appearing in the donor, who will always say if he feels faint.

This method has been employed in this hospital on more than one occasion with good results.

The drawbacks to direct transfusion of blood are considerable.

1. It is difficult in a country like Macedonia to find a healthy donor, for most men have either consciously or unconsciously had malaria.

2. There are constitutional or acquired diseases to be borne in mind in the case of the donor.

3. Men cannot often afford to give blood in the climate and conditions that obtain in a district like Salonika.

B. **Local Effects.**—Four chief local effects have been noticed in large wounds. They are as follows:

1. *A Tendency to Bleed.*—This has taken the form of a generalised oozing from small capillaries, and is especially noticeable in those cases which have concomitant jaundice. This bleeding may last a considerable time, and is liable to occur after operation in such cases as radical cure of hernia, appendicectomy, and the like. Hence it is inadvisable to perform operations of election on anybody soon after an attack of malaria. It is more important to wait until the patient has had treatment for at least a month.

2. In many cases it has been noticed that while wounds appear to be progressing favourably, especially those being prepared for secondary suture, a halt takes place, and the wound surfaces become pale and covered with a glairy, sticky substance somewhat like mucus. No further healing occurs until quinine is exhibited, when the condition passes off, the wound rapidly sterilises and becomes fit for secondary suture. No other signs of malaria are present. Should the administration of quinine be delayed, the wound eventually assumes the guise of an ulcer with punched-out edges and a serpiginous margin. These ulcers in many respects resemble syphilis. They rapidly tend to heal upon the exhibition of quinine.

3. In a number of cases, especially of large wounds, it was observed that

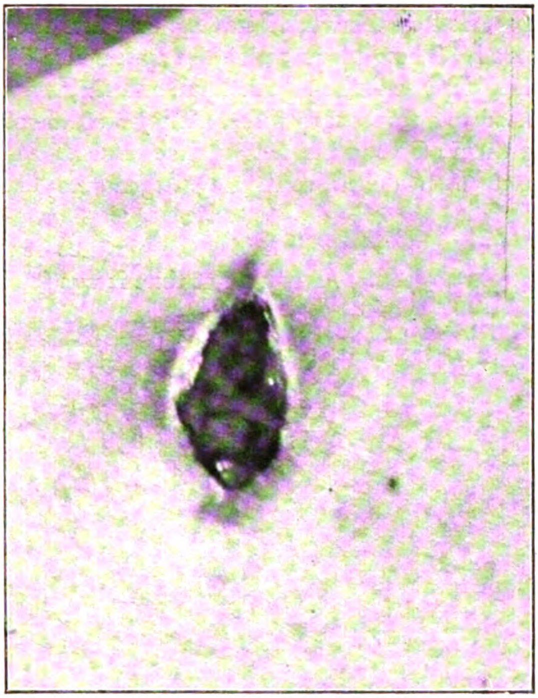


FIG. 60.—Wound of back complicated by malaria.

Note the deeply cut edges of the ulcer. The wound is healing under the influence of intramuscular quinine. This patient had ten attacks of malaria within twelve months.

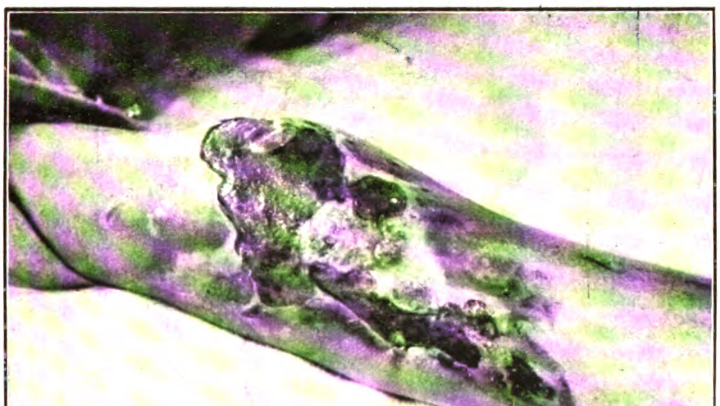


FIG. 61.—Large wound of lower extremity involving knee-joint.

Note the punched-out appearance of the ulcer and its serpiginous outline. Note also the presence of plaques upon the surface of the wound. This condition, though closely resembling syphilis, is commonly seen when malaria complicates a wound.

white plaques appeared on the wound surface. At first their significance was not understood. These plaques give the appearance of raised white patches resembling dead or sodden epithelium, and they vary in size from that of a pin's head to a threepenny piece. They are difficult to remove, and on scraping them off a red bleeding surface results. Microscopically they show structureless débris containing degenerate leucocytes and irregular granules.

There did not appear to be a cause for the presence of these plaques when first they were noticed. After a short time it was found that their

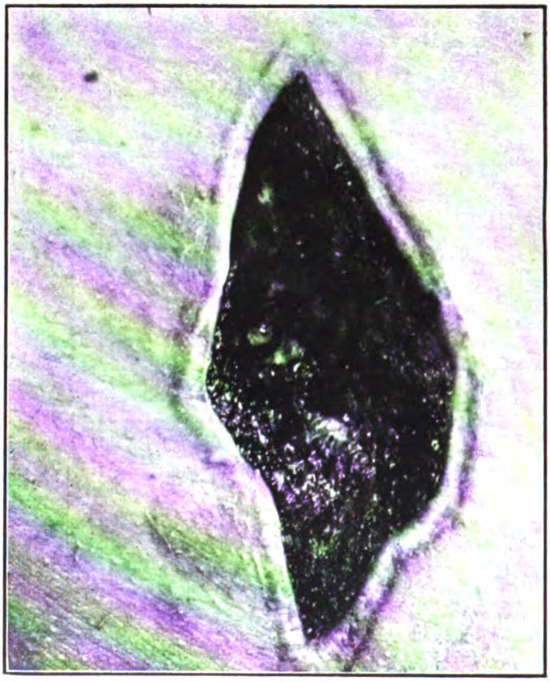


FIG. 62.—Indolent condition in a wound the result of malaria.
This patient had nine attacks within the year. Note the sharply cut edges of a wound that has now assumed the form of an indolent ulcer.

appearance was, as a general rule, followed within forty-eight hours by an attack of malaria. When the malaria was treated vigorously the plaques disappeared. After this had been recognised the patient, on the appearance of these patches, if not already taking quinine, was given it, or his dose was increased if already under treatment. The result was the disappearance of the plaques, and their replacement by healthy granulation tissue. The attack of malaria, as a rule, was aborted, and the wound again assumed a healthy appearance.

4. A red, swollen, painless, erysipelatous condition, not only of the wound itself, but also of the skin and subcutaneous tissues at some distance from

the wound, has not been an uncommon occurrence. It has been strongly argued that this complication is due to sepsis. Our answer to this argument is, that if it be due to sepsis, then such sepsis occurring in a wound under-

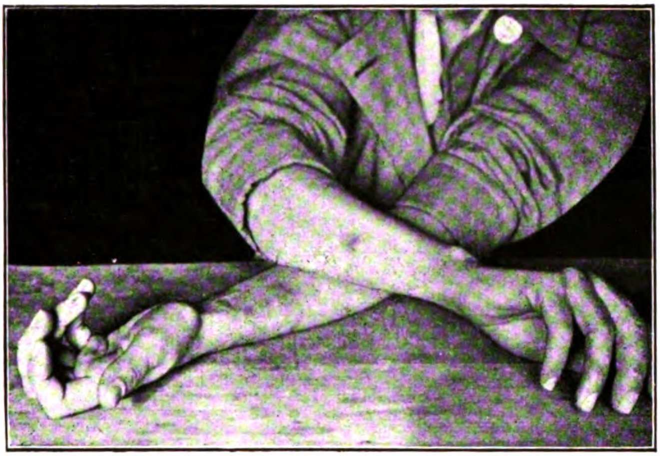


FIG. 63.—Chronic sores on forearms (? Veldt sores).
Cure resulted on administration of quinine.

going an uncomplicated course of continuous sterilisation, with favourable bacteriological reports, is but the symptom of some underlying condition. In all these cases, some fifteen in number, the onset of this angry

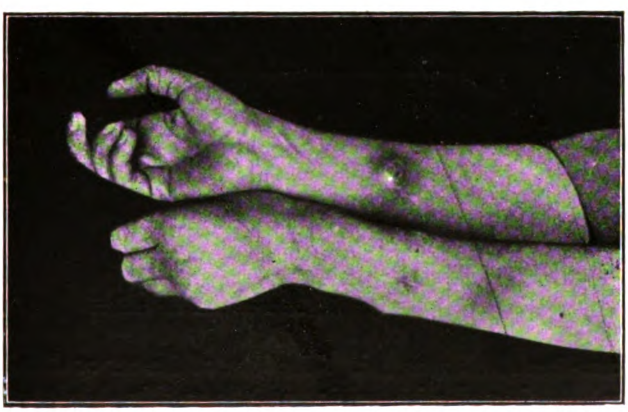


FIG. 64.—Indolent boils (? Veldt sores) of forearms containing caseous material in a patient who has had many attacks of malaria.
Condition improved and cure resulted after administration of quinine.

erysipelatous condition has been ushered in with a shivering fit, severe headache, followed by a sweat, with or without vomiting. In nine of these fifteen cases the malarial parasite was found, but in every case,

without exception, the temperature settled and the erysipelatous condition totally subsided within forty-eight to seventy-two hours on the exhibition of quinine. These cases are too numerous to be coincidences; hence I think it may fairly be taken for granted that such a set-back to a wound is malarial in its origin.

The accompanying plate illustrates the condition shown in these fifteen cases.

Examination of the Blood for Malaria.—In ordinary cases the best time to make the blood-film is when the temperature is dropping, for then the parasite is relatively large and easily seen, and the type can be better determined. In many cases, however, of mixed infection and of malignant tertian, or even very heavy benign tertian infection, and of malaria following wounds, the temperature does not drop at once, and films should be made as early as possible, preferably before any quinine has been given. The administration of quinine has a very profound effect in diminishing the numbers of parasites in the peripheral blood, making it difficult or impossible to find the parasites in a blood-film. The film should be made by the method illustrated. This has been found to give the most uniformly satisfactory results in this hospital, where at the time of writing over 200 blood-films are examined each week.

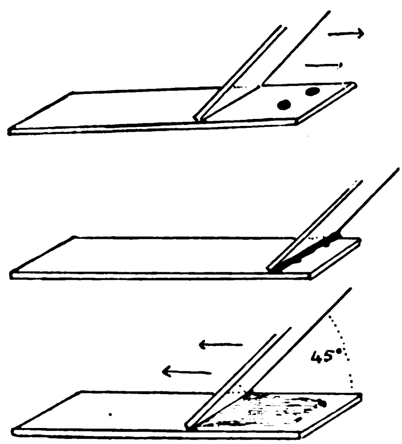


Fig. 65.—Making a blood smear for examination for malarial parasites.

Two grease-free slides are used. The lobe of the ear or distal phalanx of the thumb is cleaned with spirit and thoroughly dried with sterile gauze or wool, or by passing the thumb through the flame of a spirit lamp. A puncture is made with a sterile needle, and two or three small drops of blood are caught on the end of one slide in the position shown. The other slide is then held with one end in contact with the first and placed about ½ inch in front of the drops. The inclination of the second slide to the first is about 50 degrees. The end of the second slide is then drawn backwards upon the first until it comes into contact with the drops

PLATE III.

Wound of leg showing a red painless erysipelatous condition of the whole leg terminating above the knee. The condition was ushered in with a rigor followed by sweating and the malarial parasite was found in the blood. The whole condition vanished in forty-eight hours on the administration of quinine intramuscularly.

To face page 218.

of blood, and the blood runs along the posterior edge of the end of the second slide. The latter is then pushed along the whole length of the first slide, and in doing so drags a film of blood along with it. Any desired thickness or thinness of the film may be got by varying the angle of inclination of the second slide to the first. By this method a perfect film can be very easily obtained. When it is examined under the microscope, it is seen that the individual blood-corpuscles are spread out separately side by side, and not crushed up or in rouleaux.

Leishman's stain has been found to give the best picture. When the slide is dry the film is covered with Leishman's stain for one minute, and then two volumes of water added. The diluted stain is left in contact with the film for fifteen minutes, and then the slide is washed and allowed to drip dry. All stages in the life-cycle of the benign tertian parasite as it occurs in man may be seen in these films, and if the parasite be older than the " ring " form, Schüffner's dots are beautifully shown surrounding the parasite in the substance of the affected corpuscle. The forms of the malignant tertian parasite commonly seen are the delicate " ring " forms and the " crescents." The quartan parasite is extremely rare, having been seen in this hospital in only four out of about 8,000 films examined, of which 50 to 60 per cent. were positive. After an attack of malaria a leucopenia is found in the blood, with a marked relative excess of mononuclears. In very many cases here where, probably owing to the previous exhibition of quinine in large doses, the parasites were not discovered, it was found that the mononuclears were increased to 70 or 80 per cent. of the total leucocytes, and there was much pigment ingested in their endoplasm. This feature was considered quite diagnostic of malaria, and the diagnosis was very often justified by subsequent developments.

The " thick film " method is very useful for detecting scanty parasites, in particular " crescents." A large drop of blood is spread out very thickly on a slide by means of a needle, allowed to dry, and then treated with acetic alcohol (glacial acetic acid 2 parts, alcohol 1 part). This fixes the film and also hæmolyses the red corpuscles, leaving the white corpuscles and parasites. The film is thereafter stained with Giemsa's stain, and examined in the usual way. " Crescents " can often be found in large numbers by this method in cases where the ordinary thin-film method fails to detect them.

Post-Mortem Findings in Fatal Cases of Malaria.—The chief organs showing gross changes in fatal cases of malaria are the heart, spleen, the liver, and often the kidneys. The heart is dilated, and the ventricle walls are thinner than normal ; the myocardium is soft and in a condition of fatty degeneration. The liver is enlarged, and here fatty degenerative changes are present. The spleen is large, soft, and diffluent, and the kidneys often show a degree of fatty degeneration.

The brain in cases dying of cerebral malaria may or may not show an engorged condition of the vessels of the pia. In nearly all cases the whole

substance of the brain is "peppered" with petechiæ and foci of thrombosis of the minute vessels. These vessels can be shown to be completely blocked by malarial parasites.

It is a point of interest to note that out of many lumbar punctures performed on comatose cases of cerebral malaria, the cerebro-spinal fluid, though usually under pressure, is quite clear, and repeated examinations by the bacteriologist have revealed nothing abnormal either as regards cell-content or bacteria. Again, none of these cases have appeared to benefit clinically in any way as the result of the puncture.

From the gross post-mortem findings alone it is easy to understand that malaria, by its destructive influence on the excretory and other organs, apart from its toxins and blood destruction, must exert a very baneful influence both on wounds and wounded men.

It might be of interest to note that out of 13,500 cases of malaria treated at this hospital, the death-rate works out at 0·48 per cent.

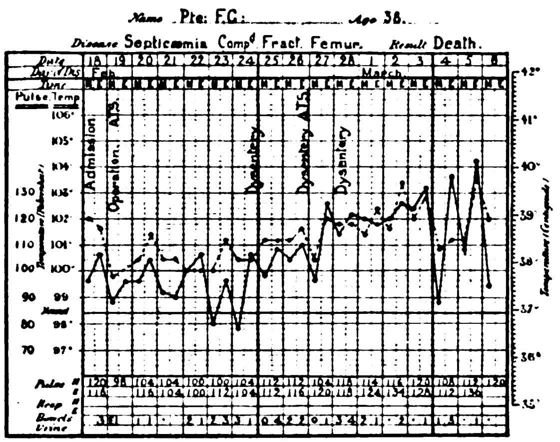


FIG. 66.—Chart showing the effect of dysentery complicating a case of septicæmia which followed a severely comminuted fracture of the femur.

Dysentery.—The effects produced in wounds by dysentery are largely due to the debilitating effects of the disease. The local effects are practically nil, except in the case of buttock and thigh wounds and abdominal wounds, in which there is likely to be contamination from the frequent stools. The number of cases in which this has occurred has been small, and it is the nursing of these cases that needs careful watching. Prompt treatment, of course, is essential.

TREATMENT OF DYSENTERY.—Preliminary purgation by castor oil is usually indicated, especially in the early stages, and thereafter sodium sulphate should be given in doses of 1 drachm hourly during the acute stage. Unless there be good grounds for suspecting the dysentery to be amœbic, antidysentery serum up to 60 c.c. should be given subcutaneously as early in the disease as possible. It is of little use even in pure Shiga and

Flexner infections after the first two days. If the toxæmia be severe, intravenous saline should be given without delay. In amœbic cases the specific treatment is, of course, emetin. Early treatment with emetin offers a very fair prospect of cure. It may be given in the form of emetin hydrochloride or of the double iodide of emetin and bismuth. The latter almost invariably causes excessive nausea and vomiting, and is, further, not now considered to be so effective in eradicating cysts from chronic cases as it was thought to be when introduced a year or two ago. It is administered by mouth in doses of 3 grains daily for twelve days, and this course is repeated once or twice after a week's interval. Emetin hydrochloride still remains the stock remedy, and according to Wenyon gives the best results. It should be given in doses of 1½ grains per day for twelve days, and the course repeated once or twice after a week's interval. One grain should be given hypodermically in the morning, and ½ grain tabloid (keratin-coated) at night.

Stools, however, containing blood and mucus must not always be taken as dysenteric unless confirmation be obtained by bacteriological examination, as many cases of malaria pass blood and mucus, and the treatment must be directed against the primary cause. Quinine must, of course, be given if the case be one of malarial colitis.

In cases of wounds of joints where dysentery is afterwards a complication it is quite possible that a dysenteric arthritis may supervene in the joint that has been wounded, as dysenteric arthritis, especially of the knee-joint, has not been by any means uncommon in Greece, but so far I have not seen a case of dysentery complicating a knee-joint wound.

Symptoms of Dysentery.—The disease is characterised by abdominal pain, distension, and vomiting, with very frequent passing of stools containing blood and mucus. Tenesmus is a constant and distressing symptom; the tongue is dry, brown, and coated; the temperature is raised often to 103°, and the patient rapidly becomes dehydrated. The actual diagnosis of dysentery, and the identification of the type rests with the bacteriologist.

Bacteriological Investigation of Dysentery.—Early examination of the blood and mucus passed is desirable to obtain good results. The macroscopic and microscopic appearance of the stool should be noted. This often gives a very fair indication of whether the case is bacillary or amœbic. The bacillary dysentery stool usually contains many more pus and other cells than the amœbic stool, and may often contain macrophages or large endothelial cells ingesting blood-corpuscles. Amœbic dysentery is a disease of the submucous coat of the colon, and the discharge contains mucus and sloughs rather than pus.

For microscopic examination for *Entamœba histolytica* a small piece of the mucus is spread out on a slide in a drop or two of saline, covered with a cover-slip, and examined with an oil-immersion lens. The diagnostic feature of the *Entamœba histolytica* is the ingestion of one or more red

blood-corpuscles within its protoplasm. This distinguishes it finally from *Amœba coli.* The pseudopodial movements are usually active, but if the amœba is seen just before encystment, movements may be sluggish, and the ingested red blood-corpuscles may have lost their colour. This is a practical point worth noting. Histolytica cysts are small, usually 10 to 14 μ in diameter, and have one, two, or four nuclei. The mature cyst, with four nuclei and chromidial bars in its protoplasm, is typical. A report on the microscopic examination of the stool can be given without delay, and if the entamœba or its cysts be found or suspected, then emetin treatment should be commenced at once. If amœbic dysentery be not definitely diagnosed, but suspected, examination of stools must be repeated daily for several days.

In all cases, whether the entamœba has been found or not, the stool should be examined for bacillary dysentery. Several pieces of the mucus should be teased out in saline in a watch-glass or Petri dish, and when thoroughly washed with saline, part of it should be transferred to another watch-glass with saline. After a second thorough washing and teasing out, a few loopfuls of the fluid with adherent small tags of mucus are plated out upon two plates of McConkey agar, and the plates incubated over-night. Next day any small colourless colonies that may be present are picked off and transplanted into a series of agar tubes. These are incubated for twenty-four hours, and any tube which shows colonies resembling the slimy semi-translucent colonies of the dysentery bacilli is tested with regard to sugar and agglutination reactions, and also as to motility. *B. dysenteriæ* (Shiga) is non-motile, and produces acid in glucose, but not in lactose, mannite, maltose, or dulcite, and it is agglutinated by a specific antiserum in at least 1 in 200 dilution. *B. dysenteriæ* (Flexner) forms acid not only in glucose, but in mannite and maltose also, but otherwise resembles Shiga's bacillus. A variant of Flexner's bacillus called *Bacillus Y.* ferments glucose and mannite, but not maltose. Each of these bacilli is agglutinated by its own specific antiserum in dilutions of not less than 1 in 200.

The examination of stools for bacillary dysentery usually takes at least two or three days before a report can be issued, and hence the specific serum treatment should be instituted at once in all suspected cases of bacillary dysentery, without waiting for the bacteriological report. Dysentery occurs mainly in epidemics, and if several cases in an epidemic have been worked out, the specific treatment required in further cases, whether serum or emetin, is usually known at the commencement.

CHAPTER XII

ANTISEPTICS

THE question of antiseptics in the treatment of the present war wound is both a vexed and important one.

The pre-war antiseptics, such as carbolic, perchloride of mercury, etc., have proved of little use in the treatment of the present war wound. They are harmful to the patients generally and to the tissues locally, when applied to large wound surfaces; they are strongly inhibitory to the leucocytes, and in the presence of serum and wound discharge they rapidly lose their bactericidal powers. In brief, they aid infection rather than prevent it, and have consequently fallen into disuse.

In selecting a suitable antiseptic for the present war wound the first important point to consider is the *general condition of the soldier both at the time of receiving his wound and when efficient surgical treatment of his wound can be carried out.*

Wounded men are usually suffering from severe shock; they are fatigued, and have often lost a considerable quantity of blood. They are therefore in a very poor condition to help themselves, as their body resistance at this stage is low.

We must therefore seek an antiseptic which is going to help the patient, and rely in the least possible degree on the patient helping himself, especially for the first few days following his infliction of the wound.

A suitable antiseptic should fulfil the following conditions:

1. It must be innocuous to the tissues. It must be remembered that damaged tissues are of low vitality; hence an antiseptic with a deleterious action upon sound tissues will not only further reduce the vitality of damaged tissues, but will also favour the spread of infection.
2. It must be non-poisonous to the individual when applied in large quantities to an extensive wound.
3. It must be innocuous to leucocytes, and not inhibit their function.
4. It must possess high bactericidal properties.
5. It must dissolve and remove sloughs.
6. It must aid and not hinder tissue repair.
7. Its action must not be delayed in the presence of serum or wound exudate.
8. It must be cheap and easily prepared.

The chief antiseptics we have employed have been the hypochlorites—viz., eusol and Dakin's solution (Daufresne's modification).

The method of preparing these solutions is appended at the end of Chapter XV. It has been argued that the hypochlorites fall short of the ideal antiseptic in that they do to a certain extent act deleteriously upon the phagocytes. This has not been our experience either clinically or microscopically.

The hypochlorites have, when applied to the very worst wounds by the method of Carrel and Dakin, brought about a rapid and complete state of sterilisation over a very large number of consecutive cases.

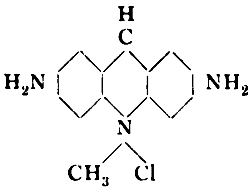
The microscopical investigation of these wounds undergoing sterilisation has been given on pp. 107–113.

It is quite possible that *in vitro* the hypochlorites may be to some degree inimical to the leucocytes, but clinically we cannot corroborate this, and we think it is doubtful if such occurs *in vivo*. If, however, it does, then we can only infer that it is but a question of degree; otherwise wounds could not possibly sterilise at the rate they do, nor would the wound show such a preponderance of healthy staining leucocytes with active phagocytosis in progress.

We have been constantly asked both by British surgeons and also by surgeons of other nationalities the following question: "How do you provide for the drainage of the wound during the time that it is undergoing sterilisation by the Carrel-Dakin method?" Our answer is that we do not wish to drain the body resources, for why drain away healthy leucocytes from any wound while they are actively phagocytic? In deep sump wounds which have, owing to the Vardar wind, been left for three days without dressing, the wound secretion at the end of this time has been wholly composed of healthy leucocytes actively phagocytic. This wound secretion is not "pus" as we understand it, for pus consists of degenerate leucocytes, broken down and digested tissue, and bacterial toxins. Further, in such sump wounds which have been full of wound secretion and hypochlorites for three successive days there has been no evening rise of temperature, which would surely be the case if such secretion was pus. On the contrary these men are fit, they eat and sleep well, and their wounds are very soon sterile. Drainage in wounds of to-day is wholly unnecessary, and we think the time has now come when this objectionable practice must be definitely abandoned.

We might add that such cases as acute suppurative appendicitis, acute liver abscess, empyema, cystitis, carbuncles, and other inflammatory conditions, have cleared up in a remarkably rapid way when treated by continuous instillations with the hypochlorites, and have given results which have been far more satisfactory than those achieved by the older methods, both as regards speed and end-results.

Flavine.—This substance is diamino-methyl-acridinium chloride, and was originally prepared by Benda at the suggestion of Ehrlich for the treat-



ment of trypanosomiasis. Its action as a strong bactericide was first pointed out by Browning and Gilmour. It is claimed by these latter observers that this substance has a strong bactericidal action in the presence of serum, and, further, that serum enhances its action.

We have given this compound a trial in 200 consecutive cases of severe gunshot wounds, using the methods both of intermittent and regular instillation with Carrel's tubes and of gauze dressings saturated with the solution, carefully and loosely packed into every crevice of the wound. In the latter method of treatment the wound and gauze have been carefully protected with sterilised jaconet prior to applying the wool and bandage. Fifty cases were submitted to intermittent instillation applied three-hourly, ½ drachm being instilled into each tube. Large wounds by this method received 2 to 3 drachms of a 1 in 1,000 dilution in normal saline three-hourly.

By intermittent three-hourly instillation of flavine into a wound we arrived at the following conclusions :

A. Clinically.—In the case of surgically prepared wounds, the wound surface soon assumes a healthy-looking aspect, becoming covered with firm rosy-red granulations. This healthy appearance of the wound surface is visible in from twenty-four to forty-eight hours after the first application. The wound progresses well up to the fourth or fifth day, when there is a halt ; the granulations become covered with a sticky mucoid substance, yellowish in colour, and evidently containing flavine.

These sticky mucoid patches have been submitted to microscopical examination, and a report on them is given in a succeeding paragraph. Let it suffice here to say they were not by any means sterile.

From this point onwards the wounds go back both clinically and bacteriologically. Clinically they become indolent, showing no further active tissue repair, and bacteriological examination shows a marked increase in the number of organisms present in the wound secretions.

B. Bacteriological Behaviour of Wounds undergoing Sterilisation by Intermittent Instillation with Flavine. — Twenty-five of these fifty wounds were investigated by the method of taking smear counts performed at two-day and three-day intervals during treatment. These wounds were of all varieties, the majority of them being compound fractures. There was a remarkable similarity in the bacteriological behaviour of the wounds as estimated by this method. The sequence of events was somewhat as follows :

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Flavine instillation was commenced at times varying from two to fifteen days after the receipt of the wound. The wounds had been excised and preliminary Carrel-Dakin treatment or eusol dressings applied at the casualty clearing station or elsewhere. On admission to the base hospital the flavine instillations were at once commenced. The wounds were all discharging and showed smear counts which varied from 2 to 40 per field.

Stage 1 : *Period of Apparent Improvement.*—During the first three days a wonderful change took place. The discharge diminished greatly, and in some cases was so small that it was difficult to scrape, even from the deepest part of the wound, sufficient material to make a smear. During this period the count of bacteria in the smears became reduced to 1 per field or less, and in many cases no organisms were seen at all. The cellular elements in the smears were scanty, and gave good staining reactions. There were a considerable proportion of endothelial and fixed tissue cells, and the number of polynuclears was relatively small. The latter must either have been prevented from entering the wound by the flavine or must have re-entered the tissues after performing phagocytosis ; and from what we know of the non-inhibitory action of 1 in 1,000 solution of flavine on the phagocytes, we cannot but conclude that the latter is what really occurred.

Stage 2 : *Indolent Period.*—During the fourth, fifth, and a few subsequent days, a sticky mucoid discharge commenced to appear. This was present particularly in the form of little gelatinous flavine-stained masses, adhering to the surface of the wound. These consisted of a heterogeneous mass of broken-down cells and débris, embedded in a matrix of fibrin. They contained numerous organisms, including in several cases a number of Gram-negative, long, slender, spore-bearing bacilli, in addition to cocci, short bacilli, and various other aerobes.

The nuclear structure was indistinct and often lost.

During this stage the smear counts varied from 2 to 20 per field ; the wounds still looked comparatively clean, but sterilisation, as shown by smear counts, could not be obtained.

Stage 3 : *Period of Retrogression.*—After the fifth to seventh day free discharge gradually reappeared. For many days these sticky gelatinous masses continued to be thrown off in the discharge. Flavine instillations were persisted in for a varying period up to the twenty-first day without a sign of improvement. Thereafter as sterilisation seemed to be indefinitely delayed, the wounds were treated by the Carrel-Dakin method. Sterilisation then proceeded uninterruptedly, and secondary suture was performed within a week or ten days after recommencing the hypochlorite.

The smear counts during the flavine retrogression period varied from 4 to 30 per field.

It may be argued that the smear-count method is not an accurate test of wound progress, as it can take no account of the virulence of the bacteria observed in the smears. It has been said that diminution in

numbers of the organisms may not necessarily be synonymous with loss of power to cause pathogenic action. In wound therapy, however, since the principle of excision of wounds is now practised almost universally, the object of all antiseptic treatment is to render the wound ready for secondary suture in the shortest possible time. Now, the only secondary suture that can at all be commended is that which results in healing by first intention. It has been proved in this hospital, over a series of nearly 2,000 cases, that such secondary suture is practicable in almost every wound. The control of secondary suture by the smear-count method has proved an unqualified success. Indeed, this method makes it possible to forecast with mathematical accuracy what the result of secondary suture will be. Accordingly, however little information the smear-count method may give regarding virulence of organisms, it yet gives all the necessary information for the successful control of secondary suture, and any further information is simply of academical interest. Hence, from the practical point of view of the surgical treatment of wounds, it is all that is required in the way of a criterion of wound progress. This criterion was not satisfied in our hands by the flavine-instillation method, and so far as this was the case the method was a failure.

In a number of the 200 cases treated by flavine, experimental secondary sutures were carried out in order to determine whether a higher bacterial count was allowable before suture in the case of a wound thoroughly impregnated with flavine. We were not able to convince ourselves that this was the case. There certainly were a very few cases in which a somewhat higher numerical standard than that adopted in the case of hypochlorite treatment did not interfere with primary union ; but these cases were the exception. Almost all of these experimental sutures were failures, and the higher the bacterial count above our standard for secondary suture, the more complete was the failure. We continue, therefore, to place complete reliance upon the smear count, properly carried out and interpreted, as a method of gauging the practical efficiency of any treatment of wounds.

The following two cases are given as examples of the results obtained by the intermittent instillation method of flavine treatment. The first is chosen as representative of compound fractures, and the second as representative of large flesh wounds. They are quite typical of this series of cases, as all presented exactly the same features.

Case 1.—Pte. A. T—— was wounded by high explosive on June 3, 1917, and admitted to the base hospital on June 6. He had a compound comminuted fracture of the neck and head of the femur, involving the hip-joint. On admission he was collapsed, and sallow and toxic in appearance. The wound was foul and exuding synovial fluid. The foreign body had been removed at the casualty clearing station.

Treatment at the Base Hospital.—The wound was explored and thoroughly opened up. Carrel tubes were inserted deep down into the wound as far as the hip-joint, and intermittent instillation with flavine

1 in 1,000 solution in saline carried out. The limb was put up in a Wallace-Maybury splint.

On admission on June 6, his smear count was 40 per field. On the 9th under flavine it fell to nil. It was nil on the 11th, 2 on the 15th, 8 on the 17th; and here there was a slight rise of temperature and free discharge from the wound. The count was 6 on the 19th, 6 on the 21st, and 8 on the 23rd.

On June 23, as the free discharge continued and the bacterial count showed no signs of diminishing, hypochlorite solution was substituted for the flavine.

The count fell to 1 on the 25th, to 0·2 on the 27th, and to nil on the 28th. Secondary suture was performed on June 28. On July 3 he was up on crutches, the limb being fixed in a Thomas's knee-splint. The wound healed absolutely by first intention.

In this case the end-result was good, but after a trial of flavine for twenty-seven days there seemed, from the amount of discharge and relatively high smear count, to be no immediate prospect of sterilisation being attained; consequently the hypochlorite was substituted, and sterilisation was then effected within five days.

Case 2.—Pte. C. H. S—— was wounded in jaw, shoulder, forearm, etc., on May 31, 1917. He sustained a very severe compound fracture of the lower jaw, with so much laceration that the tongue protruded through the wound in the neck. He had in addition a large flesh wound of the forearm measuring 4 inches by 3 inches, and a large flesh wound of the shoulder and upper arm with denudation of skin surface over an area 12 inches by 6 inches. He was admitted to the base hospital on June 9, 1917.

The jaw was treated by the Carrel-Dakin method, and was sutured on June 12 while the smear count was still as high as 6 per field. It healed *per primam*. (N.B.—This high bacterial standard applies only to wounds of the jaw.)

The huge shoulder wound was treated by flavine applied by means of Carrel's tubes.

On admission on June 9, the smear count was 40 per field. It was 30 on the 11th, 2 on the 12th, and nil on the 15th. It then rose to 3 on the 17th; it was 4 on the 19th, 5 on the 21st, and 12 on the 23rd.

On the 23rd hypochlorite was substituted for the flavine. On June 25, the smear count was 15. It fell to 8 on the 27th, and to 0·2 on the 28th. It was sutured on June 28, and healed *per primam*, although the tension was very great.

In this case the flavine was tried for fourteen days, and as the discharge was then copious and contained numerous little gelatinous masses, as the bacterial count was steadily increasing, and as the wound showed no tendency to sterilisation, the Carrel-Dakin method was substituted. Sterilisation was then attained in five days more, and the secondary suture was completely successful.

By using flavine on gauze loosely applied to a surgically prepared wound and changing the dressing twice in twenty-four hours, carefully sponging the wound surface with swabs wrung out of the antiseptic before each successive dressing, the following observations were made :

A. Clinically.—The wound progressed well up to the fifth or sixth day. The surface was particularly dry, very little wound discharge being seen. The granulations were of a firm, healthy, rose-red colour. The temperature rapidly fell, and the patient's general condition corresponded with the change seen in his wound. After the fifth to the sixth day the wound came to a standstill, and unless the antiseptic was changed it rapidly became reinfected. The wound discharge increased in amount, and the result was what we now look upon as "indolent," resembling in nature the old second-intention wound discharging "laudable pus."

B. Bacteriologically.—The results were very similar, but on the whole rather better than those obtained by the intermittent instillation method. The bacterial smear count fell almost to nil during the first five or six days, but, unlike the similar stage in hypochlorite treatment, the spore-bearing organisms and bacilli of the perfringens type did not altogether disappear. The formation of a gelatinous membrane and masses on the wound surface was not quite so obvious, but was present in lesser degree. After the sixth day free discharge recommenced and the bacterial count again rose. It remained in most cases at a level of 5 to 10 per field for a considerable time, until the flavine was replaced by another antiseptic. The leucocytes in the discharge showed good healthy staining reactions, and gave, in considerable degree, Bond's iodophil reaction test for healthy phagocytic function. But the one outstanding objection always remained that, except in the case of the smaller flesh wounds, a sufficient degree of sterilisation could not be readily attained to permit of a good result from secondary suture.

Application to Septic Wounds of the Skin and Septic Skin Conditions such as Boils, Abscesses, etc.—When applied to septic cuts, boils, abscesses, and the like, flavine has given excellent results. The wounds both clean up and heal rapidly, leaving the minimum amount of scar tissue. In quite a number of these cases, which are purely cases of a staphylococcic infection, we have been able to suture these breaches in the skin in from four to five days, and they have healed by first intention, thus saving time and the formation of an excessive amount of scar tissue.

Use of Flavine in Dirty Gunshot Wounds.—A number of wounds have reached the base hospital in a dirty condition, but at a date too late for a complete excision to be undertaken. Into fifteen such wounds we instilled flavine, to ten we applied gauze soaked in the antiseptic and loosely packed into every recess of the wound surface.

Bacteriological examination of all these wounds showed *B. perfringens* to be present, with streptococci and staphylococci, besides a number of other organisms.

By both these methods the results were equally unsatisfactory, in that sloughs were very slow to separate, sterilisation was very incomplete at the end of four to five days, and at this juncture the wounds appeared to come to a standstill in a very highly infected condition.

We have used flavine with success in five cases of severe compound fracture of the femur and in four cases of gunshot wounds of the knee-joint, where the bacterial count of the wound discharge as shown by smears did not exceed 1 to 2 organisms per field, and these cocci. In the case of the fractured femora, all of them the result of high explosive, the wounds had been excised at the casualty clearing stations and the Carrel-Dakin treatment commenced. After arrival at the base hospital, where the bacteriological count was immediately carried out, flavine was substituted for the hypochlorites.

In two cases the count was 3 and 4 organisms per field respectively. After two days' treatment with flavine the count had fallen to 2 organisms per 4 fields. This was six days after injury. The wounds were immediately sutured over flavine, and healed *per primam*. Both these patients were up on crutches, with some bony union and their wounds soundly healed, at the end of the twenty-fifth day from the date of their injury.

Of the three other cases, one man had sustained a compound fracture of both his femora, with compound fracture of the tibia and fibula on the right side, continuity in the femur still being preserved on one side ; whereas the other two had suffered unilateral fractures.

The former patient had five large wounds of excision ; the latter two had a large wound each. The bacterial count of these wounds on arrival at the base hospital was in the case of the former 1 per field, 1 per 2 fields, and 2 per 3 fields respectively.

All these wounds were immediately sutured, and healed *per primam*, with one exception—namely, the wound involving the tibia and fibula, which gaped but slightly. This last-named fracture showed extreme comminution.

In the four cases of knee-joint injury, all showed a healthy leucocytosis in the joint exudation, one case showing a mild infection with *Staphylococcus aureus*. In each of these cases a foreign body was present in the joint cavity, and was removed. Five cubic centimetres of a 1 in 1,000 solution of flavine were left in the joint cavity. The wound was sutured completely both as regards capsule and skin, some flavine being included in the skin wound. The results were highly satisfactory, all of these four cases recovering with sound movable joints, walking quite well at the end of five weeks, and it was not necessary for them to leave the country.

Some fifty cases of large flesh wounds have, after sterilisation by the Carrel-Dakin method been sutured over flavine. They have healed in all except five cases *per primam*, these five showing some separation of the wound surface in parts only. The results from performing secondary suture in these cases over flavine have been no better than when the

suture has been performed without the inclusion of any antiseptic in the wound.

Flavine has been used in the form of pastes, this compound being rubbed into the resulting wound surface after early and complete excision of a wound. This inunction of the wound is followed by primary suture, and satisfactory results have been claimed by some surgeons.

There is, however, no work yet published giving either the end-results of these cases or the percentage of successes and failures.

The fact that flavine seems to lose its highly antiseptic properties in wounds within a short interval of time (usually four to five days)—for this has, after every care and precaution, been our experience—is difficult to explain. Perhaps the tissues may develop a rapid immunity to the antiseptic. This is but a suggestion, for we have undertaken no work either to prove or disprove the idea. Again, in this climate where malaria and dysentery abound, flavine may not produce the same results as it would do in more healthy surroundings. The salient fact, however, stands out that serious gunshot wounds after excision improve rapidly for four to five days on flavine, but at the end of this period they become retrogressive both bacteriologically and clinically. Again, we have not observed the rapid spreading in of the epithelium from the skin edges which has been described by others in wounds undergoing treatment with this antiseptic.

It is quite possible that flavine may be highly bactericidal to certain organisms, but less harmful to others. We know that different organisms exist in the same wound symbiotically, and if this symbiosis can by any antiseptic be broken up, then the whole nature of the infection and its method of spread may be profoundly altered.

The conclusions we have then arrived at from the use of flavine tried in 200 consecutive cases of severe gunshot injury are as follows:

A. Clinically.—1. Flavine in a dilution of 1 in 1,000 in normal saline rapidly diminishes the residual infection in a surgically excised wound up to the fourth or fifth day, but after this period its action as an antiseptic is retrogressive. In the instance of dirty wounds containing large sloughs flavine has proved to be of little use.

2. In an excised wound, the wound secretions for the first four days are minimal in amount, the granulations are of a firm character and a healthy rosy-red colour, quite different from the granulations in wounds treated with other antiseptics. At the same time, the rate of the formation of these healthy granulations is extremely rapid. This, again, appears to slow down after the fourth or fifth day.

3. When used immediately consequent to the Carrel-Dakin treatment for the twenty-four hours prior to secondary suture, the wound has appeared dryer and has healed well after suture, but no better than in similar cases where flavine was not employed.

4. In primary closure of wounds after excision flavine has been used

and left in the wound after suture. In a small percentage the wounds have healed, but this percentage is far below that seen when secondary suture has been performed after complete sterilisation of the wound by the Carrel-Dakin process.

5. In five cases of compound fracture of the femur good results have followed the use of flavine after a course of four to five days' treatment by the Carrel-Dakin system. In four cases of penetrating knee-joint injury, flavine has been left in the joint cavity after extraction of the foreign body prior to closure of the capsule. Results in these few cases, though highly satisfactory, are no better than those obtained by methods previously in use and described in later chapters.

6. In all cases of serious gunshot wounds the Carrel-Dakin treatment has proved so rapid and satisfactory from every point of view over now 2,000 consecutive serious cases that we see no reason to deviate in any way from its use; and though flavine has, in conjunction with the Carrel-Dakin system, given good results in 200 consecutive cases, yet this latter addition has not in any way influenced the results either in speed or quality, and at present we see no reason for adopting an expensive adjunct to what has already proved both a cheap and efficient course of treatment.

B. Bacteriologically.—1. In wounds treated by flavine instilled intermittently through Carrel's tubes, the smear-count method showed a great diminution in the number of bacteria during the first four to six days. Polynuclear cells disappeared from the wound and apparently re-entered the circulation after performing phagocytosis. After the sixth day the bacterial count gradually became increased, and polynuclear cells reappeared in considerable numbers in the discharge. The number of spore-bearing organisms in these latter smears was relatively increased. The phagocytes, judged by every standard, were healthy and active. The wounds, however, did not become sterilised, at least not within a reasonable period of from three to four weeks.

2. In wounds treated by the flavine gauze method the results were similar, but rather better. After a preliminary period of diminished bacterial counts, there came a stage of retrogression when the counts remained high. Sterilisation was not obtained within a reasonable period, except in the case of the smallest flesh wounds.

3. In primary and secondary sutures over flavine 1 in 1,000 solution (the solution being left in the wound) primary union has in a number of cases been obtained with bacterial counts averaging up to 2 per field. With higher bacterial counts the method was a failure. This standard is somewhat higher than that adopted here for secondary suture after sterilisation by the Carrel-Dakin process, but primary union in the flavine cases was not a mathematically certain result. The flavine solution appeared to have a slightly beneficial action when so employed in wounds at the time of suture.

Brilliant Green.—We have tried this antiseptic in fifty consecutive

cases of gunshot wounds and would have given it a further trial had more of the antiseptic been available.

Like flavine, it was tried both by the method of regular intermittent instillation by means of Carrel's tubes and by application on gauze, the gauze being carefully packed into all the wound diverticula. We have also used it in a few cases of primary suture after excision of the wound.

The results have been as follows :

Twenty-five excised wounds were submitted to intermittent instillation. Of these, fifteen were submitted to secondary suture at the end of the fifth day, when the count of organisms per field was 2 to 3. After suture was complete, 1 or 2 drachms of the antiseptic were forced into the sutured wound between the stitches. In eight of these cases primary union occurred. Of the remaining seven, four developed malaria, and the wound showed a degree of infection which rapidly subsided on the exhibition of quinine. The wounds completely broke down and gaped in the remaining three cases, two of which had typical malarial attacks. Of the eight cases that healed *per primam*, one was associated with compound fracture of the femur, two with compound fracture of the humerus, the remainder being large flesh wounds.

The remaining ten cases of these twenty-five showed a tendency to come to a standstill after the fifth day, and the antiseptic was changed, the hypochlorites being substituted. The latter antiseptic rapidly brought about sterilisation, and the wounds were sutured.

Twenty-five excised wounds were treated by the application of the antiseptic on gauze. The wounds clinically remained remarkably clean, but in not one case did the bacterial count reach the low standard necessary for secondary suture. After the fifth day the bacterial count rose, and there was more discharge from the wound surface. Eight of these wounds were submitted to secondary suture when the count was 7 to 8 per field ; and although five of them held, yet there was considerable discharge both from the line of suture and the stitch-holes which lasted for five or six days after the operation, although brilliant green solution was instilled into these sutured wounds daily through a Carrel's tube which had been included in the wound for this purpose.

The remaining three wounds entirely broke down after suture, but two of these patients developed malaria directly after the operation for suture had been carried out.

The remaining seventeen cases of this series were after the fifth day treated by the Carrel-Dakin method. Their wounds rapidly sterilised, and secondary suture was performed.

It has struck us that out of this small series of fifty cases, the action of brilliant green is much the same as flavine, but there are important differences. The character of the wound granulations is different, for they are certainly firmer, redder, and more healthy-looking in the wounds treated with brilliant green. Again, we have not noticed, in wounds undergoing

treatment with brilliant green, the sticky coagulum which was almost universally present in the flavine cases. Lastly, the bacterial count falls more rapidly—that is, the rate of sterilisation of a wound up to a point has been more rapid in the case of brilliant green than in the case of flavine.

We have sutured twenty wounds with a high bacterial count, 10 per field and over, after thoroughly swabbing them with brilliant green. Carrel's tubes have been included to the depth of these sutured wounds, and brilliant green has been instilled into the wound twice daily, just as in the case of flavine. Results attending this method have been unsatisfactory, primary union only occurring in two. In ten of the remaining cases the wounds held together in parts and eventually healed, but in the remaining eight cases the wounds entirely opened.

In no case have we seen any harm follow the use of flavine or brilliant green, either locally or generally.

We have in a number of cases swabbed wounds which have been sterilised by the Carrel-Dakin method with brilliant green prior to secondary suture, and though these wounds have healed *per primam*, the result was no better than in many other cases in which this antiseptic was not employed.

We are again at a loss to explain why it is that wounds undergoing sterilisation with brilliant green suddenly come to a standstill at the end of the fifth or sixth day, just as they do in the case of flavine.

We have had but little opportunity to submit wounds to primary suture after excision, as by the time this base hospital has been reached it has been too late. We have, however, had opportunities of trying primary suture over brilliant green in six cases of gunshot injuries. These cases were all admitted within four hours of the receipt of the wounds.

The results were very encouraging, as five of the six cases, two of them being complicated by compound comminuted fracture of the tibia, healed by primary union. These two men were up and walking at the end of eight weeks. Here, again, we have obtained equally good results in a number of cases submitted to primary suture where a Carrel's tube has been included in the wound, and instillation of the hypochlorites has been carried out six-hourly for forty-eight hours, when the tube has been omitted. An article of much interest is published in the *British Medical Journal* of October 6, 1917, by Captain Hey, R.A.M.C., on "The Early Closure of Gunshot Wounds." Captain Hey has devised and used a paste with the following formula:

Boric acid	11 ounces
French chalk	1 ounce
Liquid paraffin	8 fluid ounces
Brilliant green	$17\frac{1}{2}$ grains

He says: "The boric acid and French chalk must first be intimately mixed in a mortar, then the liquid paraffin worked in, and finally the brilliant green dissolved in rectified spirit."

We have as yet had no opportunity of trying this paste, but from results obtained from primary suture over brilliant green solution of strength 1 in 1,000, we can quite conceive that good results would follow its use, as Captain Hey has proved.

Bismuth, Iodoform, and Paraffin Paste.—Although we have not personally given this compound a trial in wound treatment, yet we have been able to observe some of the results of others.

Certain surgeons, after bringing a wound to a degree of sterilisation by other methods of treatment, have thoroughly rubbed the wound surface with small quantities of this compound, and obtained satisfactory union after suture. This method has been applied to cases of compound fracture, and satisfactory results reported. The compound has also been employed in cases submitted to primary suture after wound excision.

All surgeons are not agreed upon the efficacy of the use of this antiseptic in wounds. Amongst a series of ten cases which we were invited to see, two were suffering from bismuth-poisoning, and two from iodoform-poisoning.

There appear to be certain drawbacks to the use of this compound :

(1) Idiosyncrasy to bismuth and iodoform.
(2) It may delay healing, so causing the wound to gape after the sutures have been removed.
(3) It may cause trouble at a later date by leaving a residue in the tissues which is opaque to the X-rays.

The antiseptics that have been universally employed at all units on this front are the hypochlorites. The antiseptic has been instilled into the wound hourly or two-hourly by the method of Carrel and Dakin. Treatment has been commenced at the casualty clearing station, and in some cases at the field ambulance. It has been continued on the hospital train, and completed at the base hospitals. Whenever an action has taken place, it has been found possible during the rush to give the greater percentage of the wounded the benefit of this treatment. Those patients who have not received it have in the main sustained only minor wounds.

At the base hospitals all patients have been kept until their wounds were soundly healed and they were able to get about. They were then, if necessary, sent to an orthopædic depot until they could either rejoin their units, or be given some duty on the lines of communication, or, if, necessary be invalided to England ; but in the latter case they had to be sound enough of limb to get about and jump into a boat, if necessary.

During the last few months we have witnessed the end-results of nearly 2,000 cases of serious gunshot wounds treated from start to finish by the method of Carrel and Dakin.

Subsequent chapters will show results and statistics of a system of continuity in treatment between firing-line and base hospital, from the date of the wound to its complete healing.

We do not in any way wish to insist on the use of any one particular antiseptic, but we do most strongly advocate a continuity in treatment. Thus, if at the advanced dressing station one antiseptic be employed, at the field ambulance another, at the casualty clearing station—after the wound has been excised—another, and a new method of applying it, and finally, if at the base hospital a still different treatment with yet another antiseptic be used, such a heterogeneous state of affairs is bound to militate strongly against the best and the quickest results.

We have found that the Carrel-Dakin system, when its continuity is not broken, is not only rapid and efficient, but is easily carried out and cheap to the State. The cost of material per patient over our own series of 2,000 cases, from the time of infliction of the wound up to the time of healing and the patient getting about, works out at seven shillings (pre-war catalogue prices), as already stated in Chapter I.

It is a rare event to get a set-back in a wound, or for a wound to come to a standstill. The patients arrive in a comfortable state at the base hospital, are put to bed, and there is no need to touch their wounds until the following day, as the instillation of the antiseptic is carried on through the night, often without waking them. In the great majority of cases, where the wound has been adequately dealt with at the clearing station, there is no further need for immediate operation, but the process of wound sterilisation is carried on until the bacteriologist reports it fit for secondary suture.

The whole process has worked out so smoothly and simply on this front, where the question of transport has been a difficult one, and the results have been so highly satisfactory, that we feel we cannot too strongly urge the Carrel-Dakin treatment for wounded men who have of necessity to be evacuated from unit to unit, unless a definitely superior treatment can be found to take its place. We do not in any way underestimate the difficulties of the treatment during transport, for we have had considerable experience in this connection both on the Western and Eastern fronts.

CHAPTER XIII

GENERAL TREATMENT OF GUNSHOT WOUNDS

SUCH an extensive subject as the general treatment of gunshot wounds must needs fall under several headings. The following main headings would seem to the authors to embrace everything :

A. The general care and personal hygiene of the soldier.
B. The treatment of the wounded man on the battlefield.
C. The treatment of the wounded man at the advanced dressing station.
D. The treatment of the wounded man at the field ambulance.
E. The treatment of the wounded man at the casualty clearing station.
F. The treatment of the wounded man at the base hospital.
G. The treatment of the wounded man at the institutions set apart for special classes of wounds.

The General Care and Personal Hygiene of the Soldier

This is a large and highly important subject. It might be said that the case of an unwounded man should not be classed or discussed in a chapter dealing with the general treatment of gunshot wounds. Our answer to such an argument is that every soldier should be looked upon as a potentially wounded man ; for although he be lucky enough to escape the sniper's bullet or a piece of shell for a considerable period, yet if he be in the line long enough, his turn, by the ordinary rules of chance, will most surely come. Never more apt than now to the men in the trenches has been the Biblical warning, " Let him that thinketh he standeth take heed lest he fall."

The general care of the soldier is the duty of the commanding officer, the medical officer, and company officers, but more especially that of the medical officer. It is for him to advise his commanding officer on matters which influence the soldier's general health, and also on the equally important prophylactic measures that should be taken against wound infection.

This simply amounts to following out a treatment for the prevention of the predisposing causes of wound infection already mentioned.

First and foremost is **Fatigue**. What can be done to combat this condition?

There are many minor important points which aid in the production of fatigue. Sores on the feet, flat-feet, metatarsalgia, sores rubbed by the equipment, and the like, all call into play additional muscular effort for their protection, and consequently a degree of superadded fatigue on that already existing.

Scabies and body vermin, by their irritant action on the skin, interfere with sleep and so aid fatigue.

This points to the importance of a thorough inspection both of the men and their clothing while out at rest, and for this reason both company and junior officers should be instructed, and acquainted with, what to look for at such an inspection.

Foot-Inspection.—As soon as a battalion arrives in rest billets, whatever the hour, a foot-inspection should be held.

Flat-feet, corns and callosities, undue length of toe-nails or ingrowing toe-nails, and sores from the rubbing of the boot, are the main points to look for. Any man so affected should be instructed to parade sick on the following day. It should be remembered that the feet of men who have been wearing gum-boots in the trenches soon get swollen and sodden, and it is often difficult at the end of a week's duty in the trenches to get the service-boot on. A march of four to five miles is then often quite sufficient to make a man very footsore, especially if he has any foot deformity.

Treatment of the Feet.—There are but few conditions of the feet that cannot be treated by the regimental medical officer. Foot affections as seen in the line come under two headings:

1. Those affecting the skin with its appendages, the commonest being friction sores, corns, callosities, ingrowing toe-nails, overgrowth of the toe-nails, hyperidrosis and bromidrosis.
2. Those affecting the deeper structures, and these include flat-foot, metatarsalgia, claw-foot, hallux valgus, hammer-toe, and sprains about the ankle-joint.

After the feet have been thoroughly washed with soap and water, the regimental medical officer can decide the course of treatment for those cases coming under the first heading. Blisters on the feet are best treated by puncture with a clean aseptic needle, evacuating the contents, and then painting over with iodine. Friction sores heal rapidly and do well with a few applications of the tincture of iodine.

Though these sores heal very rapidly they are apt to recur unless precautions are taken to remove the cause. The two chief causes are worn-out socks and deficiencies in the boot. New socks can always be obtained in lieu of those which are unfit for wear, and it is always a good plan to

soap new socks before wearing them, and to include in the soap a small percentage of boracic powder.

Fig. 67. (*a*)

Fig. 68. (*b*)

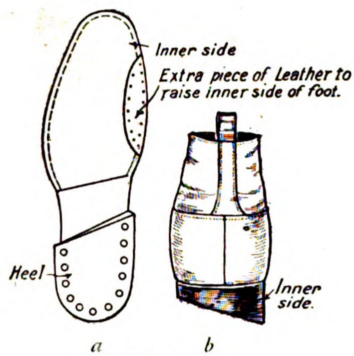


Fig. 69.

Figs. 67 and 68.—(*a*) Inner side and (*b*) outer side of boot with inner side of sole and heel raised for the relief of flat-foot.

Fig. 69.—Similar boot seen from *a* below and *b* behind.

Cases of foot affections coming under Class 2 can, as a rule, be treated by some alteration to the boot. Thus flat-foot, which is always exaggerated by trench life and the wearing of gum-boots, can be compensated by raising the inner side of the sole and heel of the boot, and extending the latter further forwards on the inner side towards the sole. The condition of flat-foot improves markedly with physical drill and exercises. It is noteworthy that men with flat-feet do not complain of the condition while they are wearing gum-boots in the trenches, yet as soon as they resume the service-boot they suffer much pain, and to march any distance is a difficulty.

Metatarsalgia and claw-foot can be treated by a leather bar placed across the sole of the foot just posterior to the ball of the toes. The weight of the body when walking is by this means taken off the ball of the toes, and the pain thereby relieved.

Both these simple alterations to the boot can be easily carried out by the battalion cobbler. Hallux valgus and hammer-toe, if the medical officer can satisfy himself that they are sufficiently severe to be causing disability, are best treated by surgical means, and the soldier must under these circumstances leave the line.

Hyperidrosis and bromidrosis are usually associated with flat-foot, and show a great tendency to improve when measures are taken for the relief of this deformity. In the line, sponging the feet with weak solutions of formalin did more good than anything else.

Bunions are generally associated with hallux valgus, and should be dealt with at the same time, and their cure results after the hallux valgus condition has been surgically corrected.

One more point before leaving the subject of the feet, and that is the fitting of the soldier with new boots. It is a golden rule always to fit a soldier with a new pair of boots directly after he comes in from a route march, for then the necessary swelling of the feet is allowed for. New boots should be thoroughly well oiled or dubbined, and if possible it is a good plan to wholly immerse them in crude oil for two or three days before issuing them to the soldier. Each man before going into trenches should be supplied with two pairs of socks—*i.e.*, an additional pair to the one he is wearing, so that he has a change when the pair he is wearing becomes impregnated with sweat, so giving the latter pair a chance to dry.

We feel that we have given but little space to the important subject of the care of the feet, but what has been said briefly embodies everything that has been met with during a considerable spell of time spent with a battalion in the trenches.

Ablution.—There is but little opportunity for ablution while doing duty in the front line, but there are usually better conveniences in the reserve line. It is, however, when the unit comes out for rest that the ideal conveniences are met with. Each division has its own baths, these being placed centrally and convenient to all units of the brigade that is out at rest. Hot and cold water with plenty of soap are provided, and during the week's rest each man gets two baths. In addition, ablution troughs are provided in the rest camps, so that every man can have a thorough wash two or three times daily.

Before going to the baths, the battalion should be inspected by the regimental medical officer, with a view to detecting scabies. Most men with this disease will parade sick, but there are some who appear to be ignorant of having the disease, and it is for the medical officer to discover them. All such cases are sent to special camps set apart for their treatment, and are returned to their units on the completion of their cure. During a prolonged period out of the trenches a battalion should be inspected twice weekly for scabies, and any doubtful cases should be treated regimentally for four or five days with sulphur ointment.

A common skin disease detected at these inspections is impetigo. The

commonest form is Bockhart's impetigo, and responds well to treatment with the unguentum hydrarg. ammon. It is probably the result of dirty underclothing chafing against the skin.

A number of cases sent out of the line and diagnosed impetigo are cases of scabies on top of which a staphylococcic infection is added. All such cases should be carefully examined for scabies at the field ambulances.

Another disease to be specially looked for at the medical officer's inspection is pediculosis pubis. This is not an uncommon condition in the trenches. A thorough washing of the pubes, followed by the application of blue ointment, is usually sufficient to cure the complaint. Shaving of the pubes has rarely been necessary.

It is most important to impress on the soldier the necessity of keeping himself clean about the pubes, perineum, and anus, for a neglected condition of cleanliness in these parts is an ever-present danger should it be here that he happens to be wounded. If he be made to realise the importance of this simple truth, he will attend to what is undoubtedly a neglected point in personal hygiene while on active service.

It is highly important that every man during the rest period should have his hair cut as short as possible all over his head. By the time the second visit to the divisional baths is due this should have taken place. There is one barber per battalion, but there are, as a rule, plenty of other men capable of cutting the hair, and their services should be enlisted. Long hair is always a danger to any man who is hit in the head.

While men are out at rest, recreations and entertainments are very important adjuncts, and it is here that the Church and Y.M.C.A. have rendered most valuable service. Rooms have been provided in which there has been an abundant supply of books, periodicals, writing material, and the like. Football matches have been instituted, the divisional band has played in the afternoons, and everything possible has been done to divert the men's attention, for the short rest period, from their arduous duties in the trenches.

Body Sores.—During the rest period all body sores, such as boils and the like, should be attended to. It is not usually necessary to send a man to hospital with these minor ailments, unless they have advanced to a condition of cellulitis. On the Western front a small incision, with evacuation of the pus, followed by an inunction of the sore with the ordinary unguentum hydrarg. (10 per cent.), has invariably been sufficient to bring about a rapid cure. On the Eastern front the condition is much more indolent, and many men reach the hospitals at the base with multiple body sores. Local treatment with ichthyol in glycerin (10 per cent.), followed by the application of scarlet-red ointment, with quinine gr. xx. daily, is the most rapid method of curing the condition, but never forget to give the quinine.

In the Eastern theatre small festering sores on the fingers are very prone to go on to inflammation of an extensive kind, involving the

interphalangeal joints and tendon sheaths, and prompt surgical action is needed for its arrest. Free incisions, followed by the Carrel-Dakin treatment, have given the best results, but one should always remember to give these patients a daily dose of 15 or 20 grains of quinine.

On the Eastern front carbuncles are common, and in addition other body sores of a kind not seen in the Western theatre. The exact nature of these latter is uncertain, and they are remarkably indolent and resistant to treatment. Some resemble the true Bagdad sore, while others are of a kind akin to syphilis. Tertiary syphilis should always be borne in mind, and a short course of treatment with potassium iodide, whilst doing no harm, will often do good towards effecting a temporary cure, and so rendering the soldier fit to carry on. Quinine alone cures a large percentage of these sores, and it is highly probable that they are malarial in origin. (See chapter by Lieut.-Colonel Smith, C.M.G.)

The Teeth.—During a period of rest, the medical officer's inspection should always include an examination of the teeth. Unfortunately, the condition of the teeth of the average fighting man is bad. We have seen mouths in which there was a collection of bad stumps quite inadequate for mastication, and a condition of pyorrhœa alveolaris far advanced. This must necessarily interfere seriously with digestion, and often these men parade sick with symptoms of gastritis. In some cases, where men have lost or broken their dentures, they have no teeth at all for masticating their food. This state of affairs interferes with the general nutrition, and these men lose weight. When the medical officer can satisfy himself that the symptoms of gastritis are genuine, and in those cases where the loss or breakage of the dentures has not been intentional, he should send these men to the dental surgeon, who visits the field ambulances on special days, to have their mouths properly attended to and new dentures fitted.

On the other hand, there are many men in the line who, despite advanced disease of their teeth, never suffer faom indigestion, and do not parade sick for this cause. They eat well, and are, physically, perfectly fit. It should, however, be remembered that a dirty state of the mouth, whether a man is physically fit or not, is a strong predisposing cause to virulent infection in a wound that he may receive in this region, and every man therefore should have impressed on him the importance of the use of a toothbrush, or, if he cannot get this, of rinsing out his mouth after each meal with water.

Constipation.—It has been stated before that men in trenches are notoriously constipated. This is in part habit, but it is also in part inhibitory. In one part of the line where one of the authors was on duty, the latrine was in a position where rifle-bullets struck all round it. On more than one occasion one went with the full desire and intention of using the latrine, but the constant ping and smack of the bullets, in close proximity, produced a complete inhibitory effect which ended in a fruit-

less journey. This, no doubt, was the case with some of the men. A number of them have been actually hit while using the latrine, and, benefiting by their experience, some of their comrades preferred to wait until they came out of the trenches.

After coming back to rest every man of the unit was on the next morning given one or two No. 9 pills; indeed, many would parade sick and ask for them. They were taken round by the medical officer's corporal, who saw that the men took them.

The day before going back to trenches a cathartic was again given to each man, and this was repeated when the men were in the reserve line.

Besides predisposing to trench ailments, constipation militates strongly against the chances of a soldier who is hit in the abdomen.

The Commoner Trench Ailments and their Treatment.

The commoner diseases met with in "trench life" are—

1. Myalgia.
2. Trench pyrexias.
3. Trench diarrhœa.
4. Trench nephritis.
5. Cardiac disorders.
6. Trench feet.

1. **Myalgia.**—Under this term are included a mixed lot of cases which in civil life would be diagnosed muscular rheumatism, lumbago, etc. During dry weather the complaint is rare, except in the more elderly men; it is most prevalent in the wet, damp months. A cause for the complaint is difficult to assign, but probably many factors are at work, the chief being *fatigue*, wet and exposure, bad teeth, and in older individuals arteriosclerosis.

A man who is tired out falls to sleep full length on a damp fire-step for two hours while his comrade is on sentry-go. When his two hours' rest has expired and he is roused to take his turn, he finds he has pain, stiffness, and aching of his muscles. This wears off with exercise. The second attack is more persistent than the first, and each succeeding attack is more persistent than the one before, until finally the condition becomes permanently established.

It is probable that a great number of these cases are in their early stages due to the inability of a tired muscle to empty itself of katabolic toxic products. After a short rest the muscle, somewhat recovering, can by its tonus get rid of a part but not all of these waste products of metabolism. There is thus a gradual accumulation of these products taking place in the muscles, until the time is reached when short rests are insufficient to produce any appreciable recovery.

If, added to this supercharging of the muscles with toxic katabolic

products, the soldier has septic foci elsewhere from which absorption is taking place—*e.g.*, a septic condition of the teeth and constipation—or if he be suffering from arterial disease, the condition is exaggerated. If this state of affairs be allowed to continue over a prolonged period, a chronic inflammation, the so-called fibrositis, is set up in the affected muscles and tissues which is very difficult and tedious of cure.

Treatment.—It should be remembered that myalgia is only a symptom, and treatment must be directed towards removal of the cause.

In the early stages all that is required is a short rest of forty-eight or seventy-two hours. Sodium salicylate or aspirin in 10-grain doses may be given three times a day and do good, and combined with this mag. sulph. ʒi. every morning. An initial aperient of one or two cathartic pills should be administered, as no doubt constipation has a part in the production of myalgia. If taken early, a man need not leave his unit for the treatment of this complaint, for this can be carried out at the transport lines.

When the disease has become established, and it becomes aggravated by changes in the weather, the soldier becomes temporarily unfit for service in the line, and he requires hospital treatment. Active massage of the affected muscles and fasciæ, followed by exercises, combined with the following prescription, thrice daily, should be tried for ten days or a fortnight :

Mag. sulph.	gr. xl.
Aspirin	gr. x.
Pot. iodid.	gr v.
Aquam	℥i.

If there be no improvement at the end of a fortnight, a mustard plaster or some other sort of blister often does good, and after the skin has recovered massage can again be practised.

During his stay in hospital the patient should be seen by the dental surgeon and any necessary treatment for the teeth should be carried out.

If, owing to the situation, the soldier cannot leave the line, a belladonna plaster will often give great relief and enable him temporarily to carry on.

2. **Trench Pyrexias.**—There are three distinct types of pyrexia met with in " trench life " :

(1) Trench fever.
(2) Pyrexia associated with diarrhœa.
(3) Pyrexia with symptoms of what is commonly called influenza.

(1) *Trench Fever.*—It is now widely believed that the infective agent of this disease is conveyed by the body louse, but when once established it can be transmitted from man to man by the blood, as first pointed out by MacNee. The disease is remittent, recurring at intervals of from four to ten days. It is characterised by its sudden onset, by pains at the back

of the eyes and in the shin-bones, with a fever running as high as 103° F. The tongue at first is usually clean, and the appetite suffers but little. It was most prevalent in a certain sector of the line during the winter of 1915-16.

Men leaving the line at this period were treated at the rest camps or the field ambulance. At the end of ten days they were returned to the line, only to relapse and again need evacuation.

For further information on this subject the reader is referred to the excellent work of MacNee.

TREATMENT.—If we are to remove the disease, it would mean the eradication of body lice, a problem yet unsolved. Much can be done, however, to minimise the number of these vermin. At the divisional baths the trousers and tunic, as already stated, are put through a Thresh, but it is doubtful if the Thresh, with the number of clothes it has to deal with in a given time, successfully kills the eggs. The female louse deposits her eggs in the seams of the trousers and the shirt. Before putting the clothes into the Thresh the seams of the trousers, especially in the region of the perineum, should be brushed out with all the eggs and fluff from the clothes. After treatment in the Thresh, and before putting the trousers on again, the seams should be thoroughly rubbed with vermigelli or Oxford grease and the shirt dusted with Oxford powder. Blankets should be frequently stoved, as these pests abound in them. After being stoved they should be lightly dusted with Oxford powder.

Unfortunately, dug-outs are badly infested with these vermin, and their disinfection is again a problem that has yet to be solved.

When once the disease is established, hospital treatment is required, although during a certain period, when the strength of the unit with which one of us was serving was low, it was necessary to treat these cases in the line.

A good aperient in the form of No. 9 pill is given, followed by 10-grain doses of aspirin or sodium salicylate, combined with quinine sulphate (gr. v.) three times a day.

The pain in the shins, which is the most persistent symptom, and which is probably due to a low form of periostitis, is best treated by massage, or, failing this, by counter-irritation.

It is a question if any medicinal remedy will prevent the onset of the disease.

Perhaps it may be a coincidence, but it is worthy of mention, that during the latter part of 1915, when the number of men contracting the complaint was increasing in a certain battalion, prophylactic doses of 5 grains of quinine per man three times a week were distributed throughout the unit, and were administered under the supervision of the company officers. The number of cases of trench fever immediately fell, and steadily diminished up to the day on which the unit left these particular trenches at the end of the year.

(2) *Pyrexia associated with Diarrhœa.*—This complaint was not at all uncommon during the winter of 1915-16. The onset is preceded by a short period of malaise and the symptoms are characterised by diarrhœa, headache, a dirty tongue, and a clammy condition of the skin, with fever as high as 103° F.

The cause of this disease is doubtful, but it has been suggested, and possibly not without grounds, that the trench rat may be responsible. It was most prevalent in a part of the line that was literally infested with rats. These animals were large, coarse creatures, and appeared to be quite fearless of human beings. They would run over the men's blankets, and on one occasion a signaller awoke to find one asleep on his neck. This will give the reader some idea of how near these animals, which might easily be carrying infection, could and would get to the soldier when asleep. They are harmless to the normal individual, but have been known to attack a wounded man while helpless.

Treatment.—One ounce of castor oil with one ounce of brandy is the quickest cure for this condition. The temperature falls rapidly, and after a night's rest is normal. The man feels slack for a day or two, but rapidly picks up. For two or three days after the fall of temperature he is given the iron and arsenic pill three times a day.

(3) *Pyrexia with Symptoms of Influenza.*—The cause of this disease is not known, but the symptoms are headache and malaise, with a temperature ranging from 101° to 102° F. The onset is sudden, and there is strong disinclination for food. The tongue is slightly coated, and the eyes are watery.

Treatment.—An aperient, No. 9 pill, followed by 10 grains of aspirin or sodium salicylate three times a day, rapidly brings down the temperature, and in forty-eight hours the soldier is fit for duty.

For the two last conditions it was hardly ever necessary for the soldier to leave the line—in fact, at this particular time in our unit the men could not have been spared. They were ultimately none the worse for remaining in the trenches, and it proved a far quicker remedy than sending them to hospital. From the highly important view of the economy of the unit, it was undoubtedly correct to treat these cases in the line at the time under consideration.

3. **Trench Diarrhœa.**—Diarrhœa is of frequent occurrence in trenches, and the cause may perhaps be that the soldier has filled his water-bottle with water from an unreliable source, or that the water in his water-bottle has in some way become contaminated. Flies, which abound in large numbers, may by contaminating the food cause the condition, or the soldier may have been eating unsound tinned salmon or fruit.

Treatment.—Castor oil with chlorodyne (♏xx.) is usually all that is required.

4. **Trench Nephritis.**—It is difficult to ascribe a cause for this complaint. By some it has been described as an infective condition, while others con-

tend that it is only a lighting up of a previously unrecognised chronic nephritis. After a thorough investigation of trench conditions, it was impossible to see how it could be ascribed to life in the trenches. Fortunately the disease is rare, and if such a disease as trench albuminuria exists as an entity, it would seem that the cause has yet to be found.

The general treatment is that of acute nephritis.

5. **Cardiac Disorders.**—Excluding cases of valvular disease of the heart, there still remains a condition associated with tachycardia with or without irregularity of the pulse. Much literature has sprung up on this subject during the present war, and articles on the " Soldier's Heart " have been numerous. This is no place for a discussion on the subject, but it is not beyond our province to suggest that the myocardium, like other muscle, is affected by fatigue, and fatigue of the myocardium was not of uncommon occurrence in the trenches.

The condition is sufficient to render a man temporarily unfit for duty in the line, and necessitates his being sent to hospital.

6. **Trench Feet.**—The subject of trench feet will be discussed in a separate chapter.

Trench Sanitation.—The sanitation of the trenches is a highly important subject from the point of view of the soldier's welfare and existence, for however unenviable and disturbing life in the trenches may be, yet there are probably worse existences if the trenches are properly looked after from a sanitary point of view.

When we speak of sanitation of the trenches, the area of ground in their immediate vicinity must also be included.

Trench Drainage.—Drainage of the trenches has always been a difficult problem. If the liquid which, through the constant rains, accumulates in the trenches consisted only of rain-water, then drainage would be a simple matter. This liquid, however, is a thick, adhesive type of mud, which will neither flow nor allow of the use of an ordinary trench pump. The constant traffic in the trenches never gives the mud a chance to settle ; consequently the water never becomes supernatant.

Sump-holes have been sunk in the side of the trench bottom, and the water which collects in these can be pumped out. More often these sump-holes are full of mud, which constantly needs ladling out by hand.

The advent of trench-grids or duck-boards was the first step towards the successful drainage of the trenches. These grids are fastened to wooden piers driven into the trench bottom. They keep the trench traffic above the mud, and by this means the mud separates into its two constituents, earth and water, the former sinking to the bottom, the latter becoming supernatant. The water collects in the sump-holes, and can be pumped out. Drainage systems that were instituted became so disorganised by enemy shell fire that they were quite inadequate to deal with the situation.

Disposal of Refuse.—Up to a certain period all trench refuse, such as

the unconsumed part of a daily ration, empty jam-tins, and the like, was thrown over the parapet or the parados, or trodden underfoot in the trench bottom. This refuse in the summer-time was an attraction for flies, which at this period abounded in great numbers. Flies are always a source of danger, and everything possible should be done to abolish them. Later, empty sandbags were hung along the trench-side, into which all refuse, such as meat-bones, bacon-rind, pieces of bread, empty jam-tins, pieces of paper, etc., was deposited. These sandbags were taken down to a dump each evening, where transport was provided for their removal to the divisional incinerators. Here this refuse was burned under the supervision of the divisional sanitary officer. Empty jam-tins or other tins that contained food were, after incineration, put to useful purposes in the making of paths, etc., in different rest camps. The larger tins, when filled with Flanders clay, made excellent bricks for the construction of battalion incinerators in the rest camps.

Trench Latrines.—The two types of trench latrine most frequently used were the bucket system and the deep-pit system, and of the two the latter was both simpler and more effective.

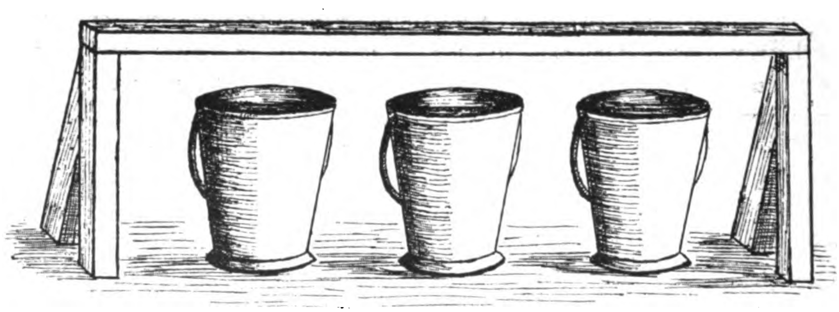


FIG. 70.—Bucket system of latrine.

The latrines are situate in small diverticula of the trench, but one big shell can obliterate the small communication between trench and latrine, and so bring about a very undesirable result. When the bucket system is adopted, each man, after using the latrine, covers his excreta with earth. Dry earth in some parts of the line was an impossibility; consequently fæces were often left uncovered in the buckets, and formed a dangerous attraction for flies. The excreta were disposed of by burial, usually in a shell-hole, a little distance behind the parados. As this ground was being constantly churned up by shell fire it can be imagined what the resulting condition of the ground would be.

These latrines were cleaned out daily, and it was important for the medical officer to see that plenty of chloride of lime and cresol was used, both in the latrine itself and in the shell-hole into which the excreta were emptied.

The deep-trench system consists of a deep trench over which are fitted a series of wooden boxes, each with a round hole through which the man defæcates. Fitting over the hole is a lid provided with a spring, and this

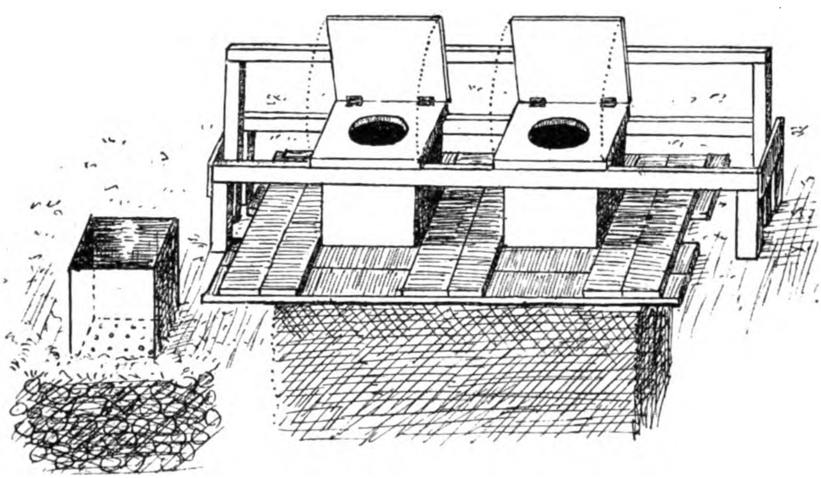


FIG. 71.—Deep-trench system of latrine.

lid automatically closes the hole after the latrine is finished with. Periodically chloride of lime is thrown into the trench with some earth to cover the excreta to a depth of 2 inches.

By this means the action of flies is eliminated, and there is far less risk of dissemination of the excreta by gun fire. Further, the excreta are never exposed and there is no smell. The boxes on which the men sit are apt to get soiled, and should be washed over with a weak solution of cresol each day. A urinal is made out of a biscuit-tin with perforations in the bottom. This tin should be placed over a hole which is in direct communication with the deep trench. In perforating these biscuit-tins for use as urinals, it should always be remembered to perforate them from within outward, so that there are no rough edges or dents within the tin around which urine can stagnate. These tins should each day be washed with a weak watery solution of cresol.

Ablution in Trenches.—Trench ablution is a difficult problem. In one part of the line ablution conveniences had with care and diligence been erected. No sooner was the work completed than a high-explosive shell scattered the whole structure. It was generally necessary to wait until the period in the support line came, for here there were better conveniences.

Disposal of the Dead.—This very important question has always found a satisfactory solution at the hands of the British for men killed in the line. After an action, when there may be many dead in No Man's Land, any bodies near the parapet have, at the risk of the living, been recovered and

taken back to a recognised plot of ground for burial. Bodies lying farther out and unrecoverable have been left. Certain saps have after an action contained dead bodies, the removal of which would entail considerable risk to the party undertaking it. Some of these, for necessary military reasons, have had to be left, though such saps have of necessity to be manned. Whenever possible, the bodies have been recovered and sent farther back for burial.

In some cases it has been absolutely necessary to fill in a sap for sanitary reasons, and whenever the exigencies allowed this was always done. Men killed in the line during quiet times were always taken back at night to the cemetery and buried 5 feet below the surface.

After the battle of —— there were many bodies, including those of other nationalities than our own, lying about the ground behind the parados and in disused trenches. These trenches were filled in, and a number of the other bodies were recovered and buried in the same trench.

Men of other nationalities than our own have, of necessity or otherwise, buried their dead in the parados or wherever they fell. This was a disastrous procedure, as the enemy fire was continually unearthing them, and it was not at all an infrequent occurrence to find limbs, or a head, or some other part of a corpse, projecting into the trench. Such a condition militates strongly against good sanitation. The farther the dead are removed from the line and the deeper they are buried, the better.

Another form of burial in the case of bodies which are in an advanced state of decomposition is to cover them with chloride of lime, and on top of this to heap a thin layer of earth.

It must never be forgotten that scattered decomposing human remains are a grave danger to a wounded man, and whenever possible such remains should be removed or covered up.

Unburied bodies, further, strongly attract flies, rats, etc., another urgent and important reason for their proper disposal.

The Feeding of the Soldier.—There is no doubt that the feeding of the British soldier during the present war has been a miracle of organisation. When one comes to look back, and to realise that in the very worst parts of the line in Flanders the appetising smell of fried bacon was present every morning while one was doing an early round of the trenches; that a fresh-meat issue each day never failed, despite the enemy's then superior artillery; that tea, bread, butter, and jam, were always to hand, in addition to comforts from home sent by the mail, which also never failed, it really should make all very thankful to, and appreciative of, those responsible for such organisation.

During spells of time in trenches it is most essential that every man should receive the greatest benefit from his ration, even to the last calorie. The human body, after all, is but a complex machine, and the fuel must be both good and sufficient if that machine is to do efficient work.

It was with a view to combating fatigue and the trench ailments that follow in its wake that the following scheme which worked smoothly and satisfactorily over a period of nearly twelve months in trenches was adopted by a certain unit.

The fresh-meat issue was kept at the transport lines, where the meat was cut off the bones, cut up into small pieces, and passed through a mincing machine. The service biscuit was soaked in brine for twenty-four hours, and was then passed through the same mincing machine. The minced meat and biscuits were then mixed together and again passed through the mincing machine. The mixture was then made up into rissoles, which were cooked on the battalion travelling cookers. If the fresh meat was short, which was rarely the case, the deficiency was made good by bully beef. These rissoles were sent up to the trenches cold in dixies and were heated up by the men in their mess-tins on spiritine stoves, which gave rise to no tell-tale smoke. This food was easy of digestion, very appetising as regards both smell and taste, and it was well suited to men whose teeth were defective.

The bones from the fresh-meat issue were all saved in the transport lines, as was also the suet. The bones were stewed on the battalion cookers, and to their extract was added Oxo cubes and a small quantity of vegetables. After skimming off the fat, this soup was put into dixies, where it set to a jelly. This was sent up to the trenches each evening without fail, so that every man about 9 p.m. had nearly a pint of hot, nourishing soup.

The suet saved at the transport lines was made up with flour and raisins, bought from the profits of the dry canteen, into plum-duff, which was sent up to the trenches and thoroughly appreciated by the men. Soup, rissoles, and the plum-duff were all served at headquarters mess, and we can testify that the whole diet was both appetising and excellent.

In addition to this diet, the men regularly received their comforts from home, and any extras they liked to buy from a dry canteen which was present in the reserve line. They also, without fail, received their tot of rum at stand-to in the morning.

By such a scheme it will be seen that practically every calorie of the ration was put to good use, it was thoroughly appreciated by both officers and men, and it quite repaid the extra bit of trouble in that the sick parade of this particular battalion was always, having regard to the existing conditions, remarkably small. The general health of the battalion, though short in numbers, kept at a high standard, and such a condition must stand a man in good stead when his time comes to be wounded. Further, there was no waste.

When leaving the trenches to go to rest billets, a hot stew was always waiting for the men at whatever hour of the day or night they might arrive.

The contents of this chapter, though not actually bearing on the treat-

ment of the wounded man, are nevertheless most important, in that such attentions as those referred to, small as they may seem, keep the man in a far better position to resist the infection which his tissues must inevitably fight if he chance to be wounded. Let it be repeated that one ounce of prevention is better than many pounds of cure, and, after all, it is the body defences that the surgeon has principally to rely on in gunshot wounds. His skill can do nothing beyond assisting the body defences, and if these be unduly weakened both surgeon and patient are severely handicapped. A surgeon may satisfactorily excise a wound, immobilise a fracture, or stitch up a perforated viscus, but if the all-important vital force is not present to back him up, his best-directed efforts must fail.

It should ever be remembered by the regimental medical officer that it is " up to him " to see to all these important points that matter, and to remember that all these details, which help to keep a man as fit as possible while he is serving in the line, give him his best and quickest chance of recovery when he is wounded.

CHAPTER XIV

GENERAL TREATMENT OF GUNSHOT WOUNDS (*Continued*).

Treatment of Wounded Men on the Battlefield

THE main points to consider in connection with the treatment of the wounded man on the battlefield are—

1. Relief of pain.
2. Arrest of hæmorrhage.
3. Temporary immobilisation of fractures.
4. Dressing of the wound.
5. Correct filling-in of the tally.
6. A short note in special cases.
7. Removal to the advanced dressing station.

1. **Relief of Pain.**—Most gunshot wounds are painless for some little time after their infliction. This is due in part to the stunning effect produced on the tissues by the missile, and in part to the degree of shock occasioned. This painless period varies from half an hour to two hours in duration, when œdema of the damaged tissues sets in. With the onset of œdema, pressure is exerted on the unyielding deep fascia, which gives rise to severe pain.

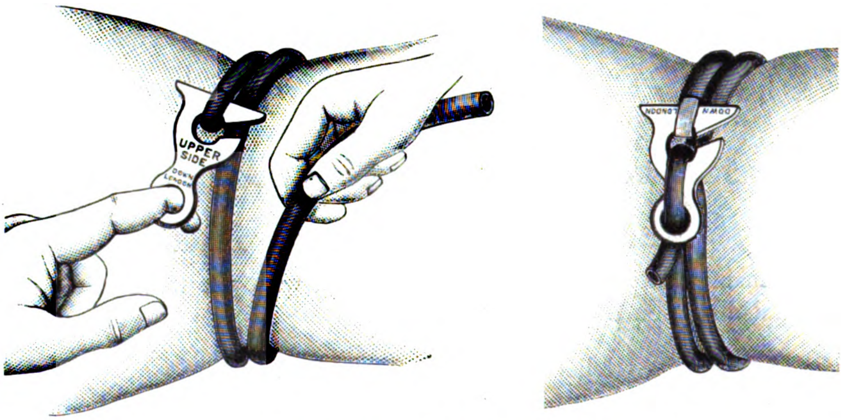
The actual blow of the missile is so rapid that the immediate effect on the individual is universally described as resembling a blow from a heavy stick.

The only remedy for the pain is morphia given hypodermically. Tablets of the drug put under the tongue are very slow in taking effect, and far less potent. Two very important precautions must be taken with regard to administering this drug, and these are—

(1) Never fail to record on the tally the dose given, and the date and time of its administration.

(2) Always before giving the drug make sure that the wounded man, especially if he be an officer, has not already taken a dose. Morphia is obtainable in book form along with other drugs, and such books are in the possession of many officers, and not only will they help themselves, but will, with the best of intentions, give a dose to a wounded man, and this without the knowledge of the medical officer.

2. **Arrest of Hæmorrhage.**—It is on the battlefield that a wounded man can least afford to lose his blood. Loss of blood not only increases the original shock occasioned by the wound, but it also aids infection by



FIGS. 72 AND 73.—A new tourniquet.
Suggested by Captain Joseph E. Adams, M.S., F.R.C.S., R.A.M.C. (T.).

seriously crippling the wounded man's resistance. Every ounce of blood is valuable at this stage, so the first care of the medical officer and stretcher-bearers should be the arrest of hæmorrhage. The importance of instructing both stretcher-bearers and combatants alike in the simple methods of stopping hæmorrhage cannot be exaggerated, for such knowledge has often meant the saving of many lives. Fortunately, large wounds do not

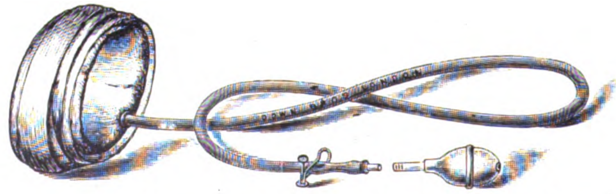


FIG. 74.—A pneumatic tourniquet for amputations, transport of wounded, etc.
Suggested by Captain J. V. Fiddian, R.A.M.C.

show a tendency to hæmorrhage immediately after their infliction, probably owing to the crushing of the divided vessels by the missile and the fall of blood-pressure occasioned by shock. A reactionary period will most surely follow if the wounded man survive; consequently, every precaution should be taken against the occurrence of a hæmorrhage during transit to the casualty clearing station. There is a small percentage of wounds which do bleed directly after their infliction, and it is all-important in dealing with these to act promptly and arrest any hæmorrhage.

It is almost incredible how much a severe primary hæmorrhage can put back the convalescence of a wounded man, and how difficult of sterilisation his wounds become. A severe compound fracture of bone in a case where a severe primary hæmorrhage has occurred is exceptionally prone to develop a fulminating osteomyelitis, costing the man his limb, if not his life.

If the hæmorrhage be from a limb, stretcher-bearers and combatants alike should be instructed to tie immediately a piece of the man's puttee around the limb, and above the wound. This done, an entrenching tool handle is passed beneath the puttee, and twisted round until the bleeding stops. Points of pressure are not to be relied upon if left to stretcher-bearers; besides, when these bearers have to carry the wounded man in, they cannot at the same time be exerting digital pressure on an artery. Another point against the use of digital pressure is that while the stretcher-bearer may be feeling for the correct spot much blood may be lost. The wounded man cannot afford the loss, neither is it giving him his best chance towards a speedy recovery.

The puttee and entrenching tool handle have never failed to arrest hæmorrhage, and any man, combatant or stretcher-bearer, can rapidly apply this simple apparatus.

Morphia (gr. $\frac{1}{4}$) is given hypodermically, and the wounded man carried down to the advanced dressing station.

Should the hæmorrhage be taking place from a wound in the neck, thorax, or abdomen, then tight plugging of the wound with cyanide gauze must be resorted to.

Hæmorrhage from the scalp can be controlled by a gauze pad covering the wound, over which pressure is exerted by means of a bandage.

In cases of badly shattered limbs, where vessels, nerves, and bone have been irretrievably damaged, it is safer, quicker, and absolutely correct treatment to amputate at once, and to go through clean tissues if possible. The operation is quite painless if done soon after infliction of the wound; the main vessels are tied, so that there is no further fear of immediate hæmorrhage, shock of transport is abolished, which is great if a limb which is useless is allowed to drag and shake for twelve miles over rough roads; a very potent focus of infection is early removed, and but little shock is occasioned by the operation if done at once. One of us has performed this operation on several occasions while in the trenches, and in not one case was there a death. The men all reached England, and were heard of later doing well.

3. Temporary Immobilisation of Fractures.—In connection with fractures of the extremities there is one important point to bear in mind, and that is, "never attempt to reduce a compound fracture, however severe, on the battlefield," for by such an effort no good can accrue, but much harm may be done.

Any fracture, whatever its nature, even if the ends of the bone be pro-

truding through the soldier's clothes, should be as perfectly immobilised as is possible *in the position in which it exists.*

Good immobilisation will stand the man in good stead against shock and pain in transport, will do much to guard against hæmorrhage before he reaches the casualty clearing station, will prevent the fractured ends of the bone from undue movement with the consequent further damage to the soft structures, and will delay the further dissemination of sepsis. These are all points of paramount importance to the future of a wounded limb.

Splints can be readily improvised, and these will be referred to in the articles dealing with the fracture of individual bones.

4. **Dressing of the Wound.**—Every soldier is provided with a first field dressing and an additional ampoule of iodine. As soon as he is wounded, he or a comrade applies the dressing. The ampoule of iodine is emptied into and around the wound, and the dressing is fixed on over this.

The first field dressing is inadequate for wounds of large size; consequently the shell dressing has been issued. The shell dressing, which is a magnified first field dressing, is carried by the stretcher-bearers, and is not issued to the soldier.

There is one important point to be remembered in the application of these dressings, and one that should be thoroughly driven home into the head of every officer and man, and that is *in every case apply the dressing loosely.*

A dressing that one would apply to a clean operation wound would be fatal if applied to a recent gunshot wound. Swelling of the wounded limb, which is always delayed, must be allowed for.

It was not at all infrequent for wounded men to arrive at a casualty clearing station with the bandage having literally eaten its way into the swollen soft parts. Not only does this cause unnecessary pain, but the bandage acts as a powerful tourniquet, restricting the circulation, and gangrene of the limb may result. This has happened on more than one occasion, and even if gangrene does not result, the vitality of the limb below the constriction is greatly impaired, and infection thereby favoured.

Yet one more important point. After the skin around the wound has been painted with iodine, a perchloride of mercury dressing must not be applied, for the combination of the two antiseptics will badly blister the skin, causing the patient additional pain and making the surgeon's task more difficult.

5. **Correct Filling-In of the Tally.**—This is an all-important point for the guidance of the medical officers from the line down to the casualty clearing stations. A correct diagnosis of gross lesions, such as a compound fracture of the femur, a penetrating or perforating wound of the knee-joint, a penetrating wound of the abdomen, and the like, are of the utmost

assistance, in that such cases are not detained at the field ambulances or the corps collecting stations, but are immediately sent on to the casualty clearing stations or other units where special conveniences exist for the treatment of particular wounds, such as penetrating abdominal injuries, penetrating wounds of the chest, etc.

Above all, it should be noted on the tally whether or not the wounded man has had morphia, and, if so, how much he has been given, and the time and date at which it was given, and whether it was given under the tongue or hypodermically, thus :

Date. Time. Morph. gr. $\frac{1}{4}$ hypoderm. or *per os*.

6. **A Short Note in Special Cases.**—Such cases are the following :

(1) Severe primary hæmorrhage.
(2) Gunshot wounds of the spine.
(3) Gunshot wounds of the head.
(4) Gunshot wounds of the abdomen.
(5) The case of an airman hit while flying.

(1) Severe Primary Hæmorrhage.—It is of the highest importance to know if a man has suffered hæmorrhage directly after being hit, and the degree of the hæmorrhage that has occurred. It has been mentioned before that a severe primary hæmorrhage strongly favours infection, and if the facts are known much can be done for such wounded men prior to and during any necessary surgical procedure which will favour their chances of a more rapid recovery.

(2) Gunshot Wounds of the Spine.—Most important information can be here given by the medical officer who sees the man directly after he is hit. The medical officer should never fail to state whether or not an interval of time, however short, existed during which the wounded man could voluntarily move his limbs, or if he had any sensation in the part of his body below the lesion. Such information is invaluable to the surgeon at the casualty clearing station or the base hospital, for by the time these latter units are reached paraplegia or paranæsthesia may be complete.

(3) Gunshot Wounds of the Head.—In these cases it is very important to know whether an interval of consciousness did or did not exist between the time of infliction of the wound and the onset of unconsciousness.

For instance, a man hit in the head walked three hundred yards to a regimental aid-post. On reaching the aid-post he lapsed into unconsciousness with stertorous breathing. Although it was broad daylight, this man was, with a short note of the condition, despatched to a special motor ambulance which took him to the casualty clearing station. The regiment was never informed of his death, so it is to be concluded that a timely operation at the casualty clearing station saved his life. If the wounded man is unconscious directly after receiving his wound, this

should be noted, for although most of these cases die in the line, yet a percentage do reach the casualty clearing stations.

(4) Gunshot Wounds of the Abdomen.—In connection with these wounds the regimental officer can again furnish valuable information. In many cases of penetrating abdominal wounds seen in the line, with the exception of those complicated by severe intra-abdominal hæmorrhage, there was little shock so long as the patient was kept quiet. There was, however, always present on palpation a definite tender area, evidently denoting the site of the damaged viscus. This localised tender area after transport was invariably lost, the tenderness and rigidity becoming diffuse and general.

The three main points in abdominal wounds to be noted by the regimental medical officer are—

(*a*) Date and hour of the wound.
(*b*) The interval of time that has elapsed between receiving the wound and the last meal taken by the soldier.
(*c*) Marking in indelible pencil on the abdominal wall the earliest area of maximum tenderness.

On arrival at the casualty clearing station the soldier, as a rule, can only give the surgeon indefinite information as to points (*a*) and (*b*).

(5) The Case of an Airman Hit while Flying.—It is important to know in this connection—

(*a*) The height at which the wound was sustained.
(*b*) The extent of the hæmorrhage.
(*c*) The exact date and time at which the man was wounded.
(*d*) The pulse-rate and general condition immediately on landing.

It is important to know the height at which the aviator was hit, because the higher he is flying, the longer it takes for the necessary equilibrium to become established after he has been forced to land. Wounded airmen have of necessity to land quickly from a rarefied atmosphere into normal atmospheric pressure, and this produces a curious effect in the wounded tissues, resembling surgical emphysema.

It is always important to know the extent of the hæmorrhage, which, in the case of airmen hit whilst flying, is always excessive.

The date and time at which the airman was hit should be noted, because it is both unwise and unsafe to attempt any operation until the circulation has again accommodated itself to the atmospheric pressure at ground level.

The pulse-rate and general condition immediately on landing are important points to note, for a man may have lost much blood, and yet this quantity may not be represented by what is seen in the machine or on his clothes. Besides, there is an idiosyncrasy to rarefied atmosphere, and it is important to know this before performing any operation.

7. **Removal to the Advanced Dressing Station.**—In most cases of injury to the upper extremity, face, scalp, and the soft structures of the lower extremities, provided that they be not extensive, the wounded man, with assistance, can walk to the advanced dressing station. It is often remarkable what some men can do in this respect who are suffering from compound fractures of the bones of the extremities. On more than one

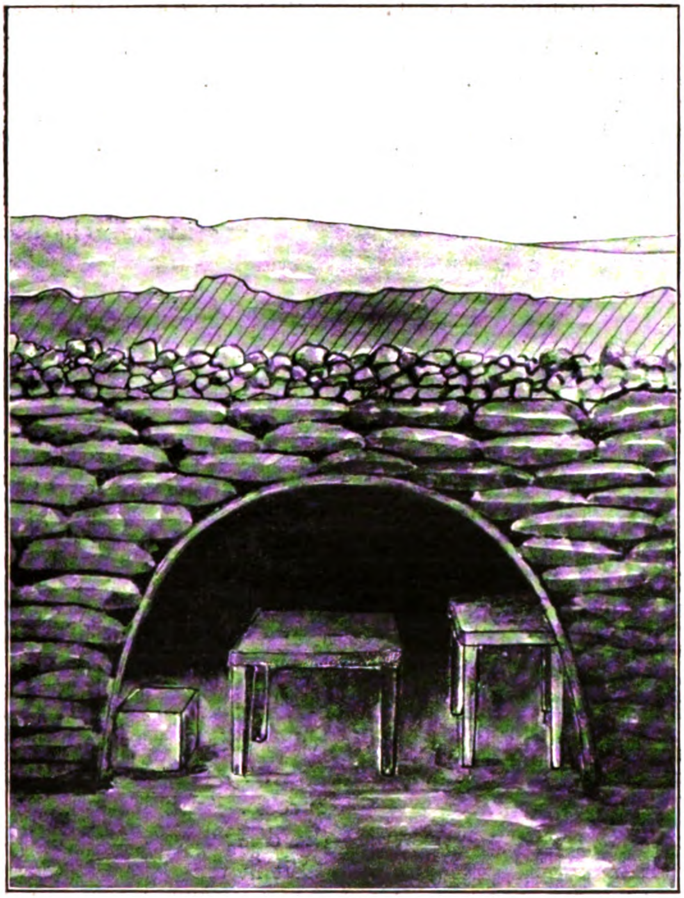


Fig. 75.—Rough drawing of an advanced dressing station.

occasion we have met a man with an arm hanging on by only a few tendons walking down a communication trench to the regimental aid-post. Men hit while in action who have sustained such severe injuries as a compound comminuted fracture of the femur have by some unknown means crawled into shell-holes or disused trenches for cover. We can recall two cases of men who, having sustained compound fracture of the tibia, had actually walked, with the aid of a comrade, nearly three hundred yards to an advanced

dressing station. On another occasion a soldier with a large loop of small intestine protruding fron a wound in the abdomen walked two hundred and fifty yards to a regimental aid-post. Soon after the infliction of a wound a man can in a large degree help himself, and when an action is in progress it is advisable not only to permit this, but to encourage it. It must never be forgotten that the wounded are an encumbrance, and their rapid evacuation from the battlefield is a matter of grave necessity. It is a golden rule to get rid first of all of cases that can walk and help themselves —that is to say, men who in a short time will probably be fit again for duty, and to leave the heavy cases who require carrying until the last. The journey from the battlefield to the advanced dressing station is of necessity rough and hazardous; it may be along a trench, it may, on the other hand, have to be undertaken in the open. Whichever route has to be taken, this part of the journey, and the work connected with it, should be as rapidly carried out as is possible, and serious cases such as head wounds, abdominal wounds, chest wounds, compound fractures of the femur, and the like, should be so labelled, and every convenience for their rapid transit to the casualty clearing station arranged for.

The Jointed-Pole Trench Stretcher.—In transport, apart from the cases which cannot be immediately reached, the chief delay occurs in the front-line trenches owing to the difficulty of passing round traverses with any kind of rigid stretcher. A short-poled stretcher held horizontally cannot pass round a right-angled corner in a trench less than 28 inches wide, and as the average size of this type of trench is 24 inches, the patient, who is carried sitting up, is tilted in all directions, and if unconscious may fall out. The strain on the bearers is very great, and their hands get knocked up. Most of the weight comes on the front bearer. Owing to their hands being occupied, they cannot save either themselves or the patient if they slip. There is therefore a risk of producing three casualties instead of one. The webbing suspension-band rucks up on the neck, producing constriction of the vessels and tiredness of the muscles.

These facts were well known by August, 1915, and many devices had been tried to obviate them, without success. This led to experiments being undertaken to try to overcome the difficulties. An article on this subject was published by Major G. H. Colt in the *Lancet* of January 22, 1916, in the hope that it would aid those at the front to design an efficient apparatus; but in this respect there has been a signal lack of success, chiefly because the subject is such a difficult one. The problem of moving a badly wounded man along a narrow front-line trench—and we do not refer to large winding communication trenches—is one of inches, both as regards the size of the trench and that of the apparatus.

The illustration shows the only practical solution of the problem. It should be particularly noted that the apparatus is shown turning a right-angled corner, the shoulders of the bearers being at right angles to one another. When the pole is straightened out there is just room for

the patient's legs. He is carried in the "Fowler" position, the best for all injuries down to the level of the knee. Below that the leg may be splinted, or a rifle splint may be applied from the hip after bringing the leg into line with the thigh.

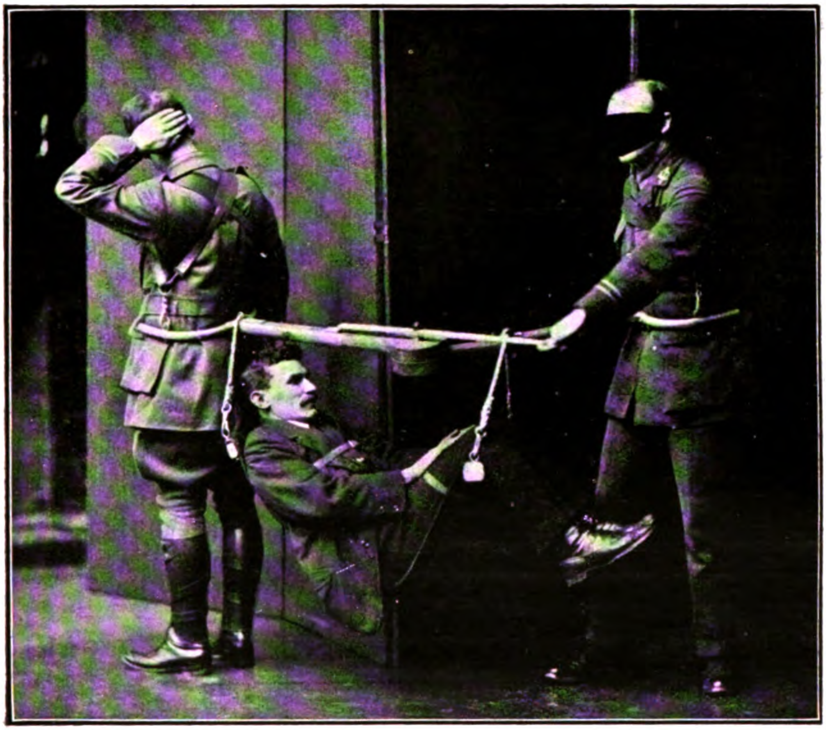


FIG. 76.—Major Colt's jointed-pole trench stretcher. Turning a right-angled corner.

For mere demonstration the apparatus is rigged up as per photograph, and the patient gets into it.
In actual use proceed as follows: Carry patient to nearest convenient place if necessary. Bearers wear shoulder-straps adjusted *in crossed position* as per photograph.
Unhasp and lay canvas on ground with head end in the direction of transit.
Lay patient on it, placing knee piece under knees.
Bearers lock the lever and hold the pole in position over the patient, and stoop down
Third man hasps up canvas portion to ropes. Both bearers lift, and third man hasps up eyelets on body girdles to shoulder suspension, and straps patient in.
Party moves off. Back bearer unlocks lever and guides round corners, holding restraint against collapse of pole.
Release in reverse order.
Rest is obtained by swinging patient sideways on to ledge of dug-out, by assistance or by crutched poles.

In this apparatus the weight is evenly distributed between the two bearers, and is borne by direct shoulder suspension; there is no constriction round the neck. The hands of the bearers are free to aid the patient or to save themselves if the ground is uneven. The use of the apparatus

has to be learnt, and this takes an average of four minutes. So far it has not been possible to raise the patient further off the ground without greatly increasing the strain on the bearers or making the apparatus too complicated, nor can a very tall man be carried unless his head is placed to one side of the pole. No doubt it will be improved with further experience. The total weight is 22 pounds. Inasmuch as it is the only apparatus so far designed that can be guaranteed to move a patient without discomfort from tilting and with ease to the bearers along new trenches of average size and construction, there will be a large sphere of usefulness for it.

Work of the Regimental Medical Officer.—The work of the regimental medical officer is perhaps the most difficult and arduous of all. He has much to think about. He has the daily sick parade, sometimes carried out in the trenches, sometimes at his regimental aid-post, the latter usually situated in no safe place.

During an action he has to work several hours on end under heavy fire, which calls for great resource and endurance, but he has ever to remember that he is doing much towards saving the lives of wounded men. This impressed itself most strongly on one of us after leaving the line to take up surgical duties at a casualty clearing station. There is not the slightest doubt that what is done for the soldier immediately after he is wounded, and the manner in which it is done, has far more influence than any subsequent treatment on the final result. The work that was done by regimental medical officers and the officers in charge of the advanced dressing stations during the Somme offensive in 1916 was, from what could be judged at the casualty clearing stations, little short of marvellous, and it was disappointing that they could not be present at these latter units to see the results of their well-directed efforts.

Treatment of the Wounded Man at the Advanced Dressing Station.—The amount of attention that can be devoted to a wounded man at the advanced dressing station depends entirely upon whether an action is in progress or not. Facilities for treating wounded men under these two different circumstances must be discussed separately.

(1) *When an Action is not in Progress.*—Under these conditions the advanced dressing station has to deal only with the daily wounded and sick from the line. The treatment consists in getting men warm, giving them, if permissible, hot drinks and food, readjusting any faulty splinting of fractured limbs, and thus thoroughly immobilising them for motor transport, and especially readjusting dressings. It must be seen to that the dressing is slackly put on before the wounded man leaves. Often by the time the motor ambulance arrives the first field dressing has, through swelling of the part, become too tight and it is of paramount importance to readjust it before the wounded man leaves the advanced dressing station.

Hæmorrhage, a not uncommon occurrence, must be arrested at this unit if necessary under an anæsthetic. It is a cardinal rule never to send a wounded man in a motor ambulance with a tourniquet applied unless it is *absolutely necessary*.

Tourniquets that have been left on for any length of time (one to two hours) have in the present war done untold harm, as cases so treated have presented gangrenous limbs on arrival at the clearing station. It is always a justifiable and correct practice to ligature any large bleeding vessel during quiet times at the advanced dressing station rather than trust to a tourniquet.

Cases of hopelessly shattered limbs, in which vessels, nerves, bone, and other structures, have been irretrievably damaged, it is far wiser to amputate, if possible, at the advanced dressing station and to ligature the main vessels. Such cases have invariably done well, shock is decreased, and the risks of hæmorrhage, further shock, and infection, are minimised during transit to the next unit.

Any treatment of the wounded man at the advanced dressing station should be carefully noted on the tally for the information of those at the next unit to which he is transferred. Before leaving, it should be ascertained that every man's rifle is unloaded, and that he has left all his ammunition behind.

(2) *When an Action is in Progress.*—During an attack or an advance the advanced dressing station has to cope with much work. Of great importance is the rapid evacuation of the wounded, either to the field ambulance or the corps collecting stations; consequently the more lightly wounded—*i.e.*, the men able to walk—should be rapidly inspected first of all. If the dressing be not tight, and if there be no hæmorrhage, these men should be sent on in batches to the next medical unit. Walking cases with larger wounds should have fresh dressings applied loosely. Any tourniquet applied on the battlefield should be removed, and any large bleeding-points clamped and ligatured.

Fractures of the upper extremity should be immobilised and the arm put up in a sling. No attempt should be made at this stage to reduce a fracture; perfect immobilisation, the application of a suitable, loosely bandaged-on dressing, and the arrest of any serious hæmorrhage, are the important points to attend to. These men can now proceed to the next medical unit.

The more serious wounds, such as head, abdominal, and chest injuries, and compound fractures of the bones of the lower extremity, next need attention.

Little can be done at this stage for head, abdominal, and chest injuries. They are stretcher cases, and will have to be carried or taken by wheel stretcher to the motor ambulance. This part of the journey should be undertaken slowly if circumstances permit, and with as little shaking as possible. Moribund cases should be kept until the last, as it is obviously

unwise to send a moribund case before one which would stand a better chance of recovery.

It may be necessary to administer more morphia before the next part of the journey is undertaken, the date, hour, and dose being written on the tally. Compound fractures of the bones of the lower extremity should be thoroughly immobilised. This is a point of vital importance. Reduction of the fracture should not be attempted, but if the limb be not thoroughly immobilised prior to transport, shock is increased, hæmorrhage may readily occur, and more damage may be done to the soft parts owing to the fractured ends of the bones having too free play in them, and as a result infection is both further disseminated and favoured.

Hot drinks may be given to all serious cases other than abdominal injuries before this part of the journey is undertaken.

When the lower limbs are hopelessly shattered, immediate amputation through the site of the injury, with ligature of the vessels, is by far the best and safest treatment, and there is no contra-indication to carrying this out at the advanced dressing station, for such cases have done well and undoubtedly lives have been saved.

Treatment at the Field Ambulance.—It has been a debated question as to whether operations should be carried out at the field ambulance. A field ambulance is a mobile unit, and an answer to the question will depend upon whether the army is advancing or not. During stationary warfare many cases have been operated upon at the field ambulances and have done well, for at these units they certainly receive earlier surgical treatment than can be the case at the casualty clearing stations. It is on the whole better not to operate upon cases at the field ambulances if they can reasonably and without risk wait until the casualty clearing station is reached. This reduces itself to operating only upon cases of extreme urgency at the field ambulance.

These cases will include the following:

(1) *Ligature of Large Arteries for Uncontrollable Hæmorrhage.*—This procedure is most necessary, and is far preferable to sending a man on a motor journey to the casualty clearing station with a tourniquet applied. The latter practice has much to condemn and nothing to recommend it.

(2) *Amputation in the Case of Hopelessly Shattered Limbs.*—At the casualty clearing station during the Somme offensive we saw several amputations that had been performed at the field ambulances. The stumps were beautifully clean, the patients extremely comfortable, and shock in these cases was a negligible quantity. Whereas in the case of badly mangled limbs which reached the casualty clearing station, shock was so pronounced and severe that a very hurried amputation had to be performed, and consequently these patients neither had so good a stump nor so good a chance of recovery as those who had received treatment at the field ambulances.

(3) *Abdominal Wounds.*—If these cases have to be operated upon, then the sooner the better. It must never be forgotten that cases of abdo-

minal injuries stand a motor journey very badly, and on this account special hospitals for their treatment were provided nearer to the line than the ordinary casualty clearing stations during and before the Somme offensive of 1916. Abdominal wounds have been operated upon at certain field ambulances, and the results have quite justified the undertaking.

Urgent cases in which intra-abdominal hæmorrhage has occurred, and which have survived to reach a field ambulance, should, if there be any hope of success, be operated upon immediately.

(4) *Tracheotomy.*—This operation should be performed early for serious wounds about the neck or jaw in which the larynx is involved.

All bandages should be inspected prior to evacuation to a casualty clearing station, in order to see that they are not too tight and are not causing constriction of the limb.

Antitetanic serum, 500 units, should be administered to every wounded man, and a record of this made on the field card, with notes of any operation that may have been performed.

Fractures should be inspected and, if necessary, appliances readjusted in order to maintain absolute immobilisation during motor transport to the casualty clearing station. This should, if possible, be done without the aid of an anæsthetic, as these wounded men have usually to undergo another operation at the clearing station, and two anæsthetics in rapid succession at this stage are badly borne.

Medical comforts in the form of beef-tea, stimulants, etc., can be given to suitable cases before undertaking the journey to the next unit.

Dressing of Wounds at the Field Ambulances.—Wherever time permits, severe wounds should have the skin around them shaved, thoroughly cleaned, and a dressing of gauze soaked in hypochlorite solution applied. If the wound be deep and open and situated on the upper aspect of the trunk, it is a good plan to fill it with eusol or Dakin's solution before applying the gauze, and after the gauze is applied to cover the dressing with jaconet which has been sterilised, prior to putting on the wool and bandage. If the wound be penetrating, it is good practice to inject the hypochlorite solution into it with a sterilised glass syringe prior to applying the dressing. A short note on the dressing and treatment of the wound should be entered on the field ambulance medical card.

The Treatment of the Wounded at the Casualty Clearing Station.—It is at the casualty clearing station that the first conveniences exist for a thorough surgical treatment of wounds. These units are situate anywhere from six to ten miles behind the line, yet the route taken by the ambulances has, owing to necessary military reasons, to be circuitous, and such a journey by road may mean anything from eight to fifteen miles.

Convoys of wounded arrive at the casualty clearing stations from the field ambulances, the corps collecting stations, and in some cases direct from the advanced dressing stations. Each man's kit and empty rifle should accompany him, but in an action this cannot always be the case, and some

kits are bound to get lost, having been either left on the battlefield or at the advanced dressing station. Nobody, except those who have witnessed it, can picture the rush and hurry at these latter places in getting the wounded away; hence the loss of some kits is inevitable.

Dealing with Convoys of Wounded at a Casualty Clearing Station.—The following method of dealing with large convoys of wounded at a casualty clearing station in France may be of interest as it worked efficiently and well over a prolonged period.

In front of the casualty clearing station there was a semicircular drive. The cars entered, discharged their burden, and then proceeded to a stretcher and blanket dump situated on one side of this drive. After taking stretchers and blankets in lieu of those left with the wounded, they left the hospital by the exit at the other end of the drive.

The wounded man's special private belongings, such as he carried in his pockets and kit, were placed in a special bag which was tied to the handle of his stretcher. Officers' kits were placed in a special pack store. The men's kits other than their special belongings were dumped.

Stretcher cases were taken first from the cars into the reception tent, walking cases were directed to a special hut set aside for the inspection of their wounds. Every stretcher case had his clothes removed in the reception tent by orderlies, and his wounds inspected by a medical officer, who decided whether his was a case needing immediate operation or not. If needing immediate operation, he had a white piece of bandage tied to the stretcher handle and he was sent to one of the operating-marquees. Men wounded in the abdomen or chest were sent direct to marquees set apart for them, and which were situate close by the operating-theatre. These men were put straight to bed and made warm with hot-water bottles for an hour or two before any necessary surgical measures were undertaken. Severe cases, such as compound fracture of the femur, cases of severe hæmorrhage, and the like, were sent to beds where every effort was made to lessen shock prior to operation.

Cases of hopeless mutilation of the limbs requiring immediate amputation were taken direct to the operating-theatre.

Cranial and special injuries were kept in special marquees, as also were all cases of shell-shock.

Wounded Germans had special marquees set apart for them, but any serious case requiring a bed was given one amongst our own wounded. A special marquee was set aside for cases arriving in a moribund condition.

A considerable number of the walking cases required surgical treatment, and these were usually attended to in a special operating-theatre. If their wounds were of a serious nature, they were transferred to the main operating-theatre.

There was a special stretcher-party working night and day between the marquees set apart for cases needing immediate operation and the theatre. After operation the surgeon decided whether the case should be

detained or whether it should be taken direct to the evacuation area. The evacuation area consisted of a number of marquees near the railway siding. All walking and all stretcher cases not requiring immediate operation were, after the dressing of their wounds, sent direct to the evacuation tents. Here they received hot drinks and other necessary medical comforts prior to entraining for the base.

Abdominal, chest, and head injuries were detained until they were fit to stand the journey.

All clothes taken off the wounded men in the reception tent were dumped, and were later sent on to the base, where presumably they were handed in to ordnance. Kits that had been dumped were similarly disposed of. Officers' kits accompanied them to the base.

The work of the casualty clearing station therefore consists in—

(1) Segregating the wounded.
(2) Carrying out necessary surgical treatment.
(3) Evacuating the wounded men who are fit to travel to the base.

These three operations may convey only a surgical significance to many, but behind them, and perhaps more important, is the enormous problem of the organisation and administration of the units which carry them out. They are units of the most expansile character, and it is only by the punctual performance by the commanding officer and his administrative staff of their highly responsible and arduous duties, that the large number of wounded who sometimes pass through a casualty clearing station in a day, can be adequately dealt with. It is difficult to credit the amount of work that is entailed in the receiving and evacuating of large numbers of wounded officers and men, or the small worries which follow, such as the loss of small articles, which in a large number of cases did not accompany the wounded man to the casualty clearing station.

The segregation of the wounded has already been referred to.

Carrying Out any Necessary Surgical Treatment.—Strictly speaking, all cases requiring surgical treatment should be operated upon at the casualty clearing station. In quiet times, when there is not an undue rush of casualties, this can always be accomplished, but when an action is in progress many cases have of necessity to be evacuated to the base although surgical treatment would have been better started at the casualty clearing station. This, of course, cannot be avoided, but it must ever be remembered that surgical treatment, though incomplete and sometimes crude through pressure of work, may save many limbs and lives if performed at the casualty clearing station, because of the time often taken by the hospital train to reach the base, and that in a few hours virulent infection may have progressed to such an extent that by the time the base is reached a limb may have to be sacrificed, if not a life.

All serious wounds should therefore be surgically treated at the

casualty clearing stations, and only wounds of lesser severity, in which there is no undue risk of any spread of infection during transit, should be sent to the base direct.

Thus, abdominal injuries, head injuries, compound fracture of the bones of the extremities, and large wounds of the soft parts, should be dealt with at the casualty clearing stations. Penetrating wounds of limbs in which there is much swelling, denoting hæmorrhage or gas gangrene, should be similarly dealt with, as also should large wounds of the face involving fracture of the jaws.

Seton wounds in which there is but little swelling, smaller flesh wounds not involving important structures, lesser cases of compound fracture of bone in which there is little or no displacement and where the wound is small—and, indeed, this class of case forms a very considerable percentage of a large batch of wounded—should, after a change of dressing, be evacuated direct to the base hospitals.

This, then, brings us to the best, quickest, and most efficient method of treating serious wounds at the casualty clearing stations. It is almost impossible to enter into such a discussion as this without first looking back and reflecting on the treatment of wounds from the earliest days of the war up to the present time.

A description of wounds as they reached England in 1914 will serve no useful purpose here. We were at that time a retreating army, and under the conditions there is no doubt that the very best was done for the wounded. During the battles of the Aisne and the Marne tetanus was not an uncommon complication of wounds, and at this time the real value of administering antitetanic serum in all cases of gunshot wounds had not been realised. To further complicate matters, the nature of modern gunshot wounds had not been grasped, though at this early period, under the then existing circumstances, no blame could be attached to anybody concerned.

At the first battle of Ypres the wounds were gruesome. At this period no definite plan of treatment had been laid down, for, indeed, the nature of these wounds was still misunderstood. Treatment was directed towards wound drainage combined with the application of the older antiseptics, such as carbolic, corrosive sublimate, hydrogen peroxide, and the like, and results were bad.

The nature of the wounds received at the second battle of Ypres and the battle of Neuve Chapelle was typical, in fact just as typical and no worse than those received in the earlier engagements, but, unfortunately, the results of treatment showed little, if any, improvement on previous work, despite the fact that all medical and surgical requirements were supplied in plenty to the casualty clearing stations and field ambulances. At this stage surgeons were working in the dark—in brief, they were still ignorant of the nature of the modern gunshot wound.

At the battle for the Aubers Ridge, which followed shortly upon the second battle of Ypres, and in the subsequent engagements in May, 1915,

certain field ambulances were administering anæsthetics to as many cases of wounded as was possible, draining the wounds with rubber tubes, removing foreign bodies, and thoroughly washing out the wounds with hydrogen peroxide. A suitable dressing was then applied, and the cases were despatched to the casualty clearing stations. During these engagements one of us was attached to one of the ambulances for surgical duties. Every wound was grossly infected, even seton wounds caused by undeviated rifle-bullets.

It must be borne in mind that the wounds received at first by the assaulting infantry are chiefly the result of machine-gun and rifle fire. The aim is directed low; consequently the majority of early wounds are confined to the lower extremities and the abdomen. It is during the counter-attack, or where reinforcements have to pass through a heavy artillery barrage, that shell wounds mostly happen.

We were taught that small in-and-out wounds caused by rifle or machine-gun bullets usually healed without any trouble, because they were sterile. Never in this war was a teaching more false, for after the engagements of May, 1915, machine-gun wounds were just as grossly infected as any other. The soft parts around and distant to the wound were acutely swollen. On opening a small seton wound with forceps, a foul-smelling, dark chocolate coloured fluid escaped, with gas. In fact, it may be truly said that these infected seton wounds were infinitely more dangerous than the large open wounds, which not only permitted the foul wound discharge to escape, but also to a great extent inhibited the growth of anaerobes.

All seton wounds, together with penetrating wounds caused by both bullets and shell, were drained with rubber tubes. The results were bad. In some of the cases the soft parts had further swollen and completely obliterated the lumen of the tube. If the lumen was not obliterated, the holes cut in the sides of the tube were; consequently there was no drainage, and the tubes only played the part of foreign bodies lodged in highly infected tissues. In the light of our present knowledge such drainage-tubes could under the best of conditions drain only a very limited extent of the wound, but in the conditions mentioned they did not even do this. They completely blocked all communication between the damaged parts and the exterior, a result which greatly favoured the growth of the anaerobes and their further destructive action on the tissues.

It was shortly after this that the quality and quantity of damage to tissue by the modern missile became known, and also the degree of infection to be dealt with, though this was not universally recognised nor agreed upon by all. Certain surgeons saw that the road to success lay in complete excision of these wounds and prolonging incisions into what appeared externally to be sound though swollen tissue, until the full extent of all damaged and swollen tissue at some distance from the wound had been exploited.

This procedure marked an important step forwards in the right direction, judging by results alone. It now remained to discover a suitable dressing for these surgically prepared wounds, and many were tried.

Irrigations, both intermittent and continuous, with different antiseptics, continuous immersion in baths, and various dressings, were all given a chance, but it seemed that at this point another serious halt had occurred. It was at this juncture that Sir Almroth Wright introduced the salt treatment, and Colonel Gray the salt pack. Results obtained by this latter treatment applied to a surgically prepared wound outdid anything previously seen, and it seemed that the long-expected cure for wounds had come at last. Salt, however, did not sterilise these wounds, and a number of cases undergoing this treatment were conspicuous by the foul smell that emanated from the salt pack, despite the fact that both the temperature and the pulse were falling satisfactorily and the wounded man was picking up.

The dressing of many of these surgically prepared wounds was extremely painful, and if multiple, a general anæsthetic was required, which not only put the wounded man back, but diminished his morale.

It remained for Carrel and Dakin to introduce an ideal antiseptic and an ideal method for its application to a surgically prepared wound. Sterilisation by the method recommended by Carrel and Dakin marks the second phase in the successful treatment of wounds.

The two cardinal points to be followed out in the treatment of all wounds are as follows:

(1) Prevent further infection.
(2) Eradicate any existing infection.

A third cardinal point in the case of compound fractures is to prevent, by thorough immobilisation, the further dissemination of infection.

The skin for a considerable distance around the wound should be thoroughly scrubbed with spirit soap and shaved. For wounds anywhere near the perineum, wounds of the upper thigh, and wounds of the buttock, the pubes, scrotum, perineum, and anal region, in addition to the skin around the wound, should be shaved, and the skin of all these parts thoroughly cleaned.

For any wound of the head, whether scalp or skull, the whole head and neck should be shaved. Wounds of the upper arm call for shaving and untold cleanliness of the axilla. For wounds about the hands and feet, especially where compound fracture of the tarsus and metatarsus exists, most scrupulous care must be devoted to cleansing; nails should be cut as short as possible, and, while the wound is protected, the foot or hand should be scrubbed with spirit soap and soda until it is clean. Turpentine and petrol may be used, if necessary, to remove any ingrained dirt. Special attention to cleanliness between the toes is extremely important.

While all this preliminary toilette of the skin is taking place the wound should be carefully protected with swabs wrung out of a suitable antiseptic. When once the skin has been satisfactorily cleaned and shaved, it should be further well rubbed over with methylated ether. Iodine is then painted on the skin for some distance around the wound prior to the next surgical step.

The authors feel that they cannot lay too great stress on the importance of cleaning and sterilising the skin and its appendages. If the leg be involved it is wise to shave the whole leg, the thigh, pubes, perineum, and anus. We have never regretted adopting this procedure, for the anus, perineum, and pubes of the average wounded man are usually extremely dirty. Nits are present in many cases, and fæces in nearly all, and whatever part of the body be wounded, such a focus, through contamination of the bed-clothing, is a source of danger. Besides, removal of this hair makes the nursing more simple, and in every way it is more cleanly and satisfactory, especially in the East.

Excision of the Wound.—After surrounding the wound with sterilised towels, excision should next be undertaken.

There are two methods of performing wound excision, and which of the two is chosen will depend entirely upon the class of wound and the amount of damage done :

A. Complete excision of the wound *en masse.*
B. Excision of the wound piecemeal.

Method A can be often applied to the following class of case :

(1) *Penetrating Shell Wounds with Extensive Damage to the Deeper Soft Structures, but not involving Bone.*—After primary excision of the wound in the skin and fascia, and prolonging incisions in either direction to expose the damaged deeper structures, an attempt is made to remove the whole of the injured and infected tissue *en masse* together with the piece of clothing and missile. This leaves a large fresh wound surface, which, though almost always inevitably infected, is far easier to sterilise than the original wound.

(2) *Extensive Lacerated Wounds of Soft Structures.*—In these wounds most of the damage is visible and not latent, as in Class 1.

Complete excision of the whole wound *en masse* is here often possible, and is a simpler procedure than the complete excision of a penetrating wound.

(3) *Wounds of the Scalp with or without Fracture of the Skull.*—Complete excision of a scalp wound *en masse*, unless an abnormal amount of scalp is involved, in which there is still vitality remaining, should be practised in every case. Should a compound fracture of the skull complicate the scalp wound, this should not deter the surgeon from performing excision *en masse*. All structures, including the pericranium, should be removed to the extent of a quarter of an inch from the wound margin. In these

cases, before proceeding to excision, it is good practice to swab the wound with pure carbolic or even to apply the actual cautery to the wound surface. This procedure prevents any weeping from the edges during excision, an occurrence which is a frequent source of reinfection and consequent failure.

(4) *Penetrating Abdominal Wounds.*—Prior to laparotomy, the penetrating wound should be excised. This may be performed in one of two ways, depending upon the relative positions of the laparotomy incision and the original wound.

(*a*) Should the laparotomy incision be planned at a distance from the penetrating wound, then the wound must be first excised, and the surgeon, after changing his gloves, will, with newly sterilised instruments, proceed to perform laparotomy.

(*b*) Should the laparotomy incision be planned to traverse the penetrating wound, then, by deviating the incision on either side of it, it can be made to include the wound, so that laparotomy and excision of the wound are performed together.

(5) *Penetrating Wounds of Joints.*—In penetrating and perforating wounds of all joints, the wound of entry and exit must be excised *en masse*, and made to include the wound in the synovial membrane.

Excision of a wound *en masse* is an extremely difficult procedure in the case of penetrating shell wounds where much damage has been sustained by the deeper structures. In the case of large lacerated wounds of the soft parts the procedure is simpler, but still in this class of case there are many difficulties and pitfalls.

Within a penetrating shell wound many pockets and diverticula exist, caused by the tearing of muscle and its subsequent retraction. The last resting-place of the missile itself in the tissues often constitutes a very awkward and difficult diverticulum to deal with.

During the process hæmorrhage occurs, and is sometimes excessive, requiring the use of many pressure forceps for its temporary arrest.

Again, when the surgeon may think that his task is finished, he may discover another diverticulum hitherto unrecognised. Excision of this may lead to a virulent reinfection of the part of the wound already excised.

Complete and successful excision of penetrating and lacerated wounds *en masse* requires much practice, patience, and experience, for in them there is at first much that the eye does not see, and much upon which the surgeon has not reckoned.

Smaller lacerated and penetrating wounds, in which there are no loculi or diverticula, are easily and rapidly excised.

If time permit, it is a good precaution—in fact, for success one might say a necessity—to sponge all these wounds with pure carbolic or some other suitable antiseptic, which will prevent any weeping of infective material from the wound surface during excision.

Excision *en masse* of wounds of the head, abdomen, and joints is easily

and rapidly carried out, but here, again, the same precaution should be taken to sear their surface with pure carbolic or the actual cautery before undertaking excision.

Could every gunshot wound, whatever its nature or class, be successfully excised *en masse*, then the surgeon's dream would be realised. We are now undoubtedly on the right road, and each day more successes are attending the efforts of those who are diligently and patiently following out this plan of campaign.

There are many set-backs yet to be overcome, and many cases in which an *en masse* excision is impossible owing to anatomical reasons. Thus, some penetrating or lacerated wounds of the thigh, leg, or upper extremity, may demand for their complete excision removal of such structures as a part of the femoral or brachial arteries, large nerve trunks, and the like. Hence in wounds such as these the method of piecemeal excision has to be adopted.

Dependent upon the successful *en masse* excision of wounds is the highly important question of *primary suture.* However careful and experienced a surgeon may be, and however thorough his technique, he cannot, when dealing with extensive wounds, by an *en masse* excision, except in an infinitesimally small number of cases, procure a bacteriologically sterile wound. The resulting wound may contain but a small dose of infection, but it is not sterile. Organisms with very small particles of devitalised tissue are bound to be left behind.

The all-important question is, can these wounds be safely closed immediately after excision if some suitable antiseptic be left in them? In other words, is primary suture practicable?

In a large percentage of cases it is. The method we have adopted has been to swab out the surgically excised wound with either brilliant green or flavine, and in doubtful cases to include in the sutured wound one or two Carrel's tubes. Ether is another useful antiseptic for this purpose. Into each of the tubes, after suture, is introduced from 1 to 3 drachms of flavine, brilliant green, or Dakin's solution, the amount instilled depending upon the size of the wound. If Dakin's solution be employed, a six-hourly instillation is carried out; but if flavine or brilliant green be used, one injection daily is sufficient. Of the three antiseptics tried over a large number of cases, Dakin's solution or eusol has given the best results. Flavine and brilliant green have been used in a dilution of 1 in 1,000, the diluent being normal saline solution. Carrel's tubes are removed from the wound in from forty-eight to seventy-two hours, provided there is no evidence of inflammation.

In cases of head injury healing occurred by primary union in forty-eight out of fifty-four cases. Of the remaining six cases, union, though delayed, occurred in four, while the remaining two cases entirely broke down. Carrel's tubes were never used for head cases; the scalp was

sutured and the antiseptic injected by means of a syringe into the wound between two of the stitches.

In most cases of penetrating wounds of knee-joints, the skin wound can with safety be closed after suturing the capsule. The skin wound before final suture is swabbed out with one of the three antiseptics, and after suture the antiseptic is instilled into the wound between two of the stitches in precisely the same manner as adopted in scalp wounds.

Out of twenty-four cases of penetrating wounds of the knee-joint treated by these means, twenty-two healed *per primam*, and two partially broke down, but only as far as the skin was concerned.

In none of these cases, and they were all wounds caused by high explosive, did the joint infection progress further.

B. Excision of a Wound Piecemeal.—This method must be resorted to when such structures as bone, large arteries, nerves, and the like, are severely involved. After all dead and ragged skin has been cleanly excised, dead muscle and other soft tissues that are obviously a source of danger are cut away, preferably with a sharp pair of scissors. Bone detached from its periosteum or bone that is soiled is also removed. It now remains to deal with large arteries or nerve trunks that have suffered.

If a large artery with its accompanying vein be exposed in a wound and be covered with infected slough, then sooner or later, however rapidly sterilisation is commenced, and however vigorously it is carried out, secondary hæmorrhage will almost always occur. This has happened time and again, and we feel convinced from our results that resection of the exposed portion of the artery and vein is the correct practice under such circumstances. Out of twenty odd cases in which this practice was resorted to, in only two did gangrene result. One of the two cases in which 3 inches of the femoral artery and vein were resected showed gangrene limited to the toes, whereas in the second case gangrene extending as high as the knee, necessitating amputation, resulted from the resection of 4 inches of the femoral artery and vein. Opposed to this, secondary hæmorrhage resulted in thirteen out of fifteen cases in which an attempt was made to save the infected artery.

When large nerve trunks are involved, every effort should be made to save them. If large nerve trunks such as the sciatic, the external popliteal, the musculo-spiral, etc., be divided, it is always advisable, if possible, after excision of the wound, to approximate the divided ends; and even if the loss of continuity be so great that apposition of the divided ends is impossible, it is advisable to bridge the gap with four or five strands of thin catgut. Whatever method be used to restore or help continuity in a divided nerve is always time well spent, because even if the anastomosis under these septic conditions is a failure, it will materially help the orthopædic surgeon when he comes to perform an anastomosis later on after the wound has healed.

The question that next arises is, what are the prospects of a successful primary suture in a wound that has been excised piecemeal? To this question it is impossible to give a definite answer. Bone that has been comminuted and infected as the result of shell fire is not only difficult to sterilise, but one can never be quite certain that all the highly infected bone has been removed; consequently the closure of such wounds by primary suture after excision is not without considerable risk. Some surgeons have had success from primary suture in this class of wound after smearing the freshly prepared wound surface and the ends of the fractured bone with various paste preparations, such as the bismuth, iodoform, and paraffin paste, brilliant-green paste, etc. We have not used these paste preparations, but have had a percentage of successes (40 per cent.) from primary suture in this class of wound by including in the wound after suture one or two Carrel's tubes and instilling Dakin's solution two-hourly, in exactly the same way as in the after-treatment of extensive wounds excised *en masse*.

It is very difficult to lay down any hard-and-fast rules for the after-treatment of large wounds excised piecemeal, but on the whole, out of a large number of cases amounting to between one and two thousand, the safest and most satisfactory results have been obtained by secondary suture, after the wound has been rendered bacteriologically sterile by the method of Carrel and Dakin.

A. **Seton Wounds.**—The inlet and exit wounds in the skin are cleanly excised, about a quarter of an inch of skin being removed all round. The incision extends down to the deep fascia. The perforation in the deep fascia is next looked for, and is frequently at a different level from the

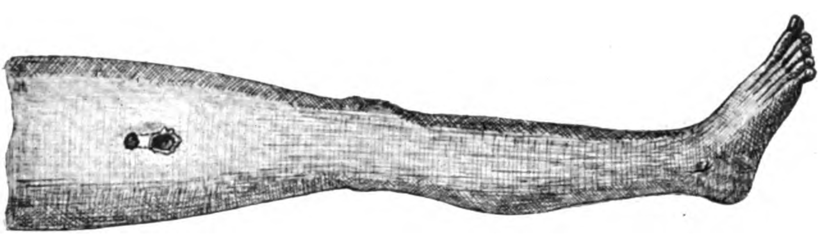


FIG. 77.—Seton wound of thigh.
Note difference in level between the perforation of the skin and that of the deep fascia.

perforation in the skin. If this be so, the skin should be incised from the excised skin wound up to the level of the perforation in the fascia.

With a clean knife the perforation in the fascia is next excised.

If the soft parts be very swollen for some considerable distance from the wound and in the neighbourhood of the wound itself, both skin and deep fascia should be further incised by prolonging the wound of excision in either direction to the required extent.

This is a most important step, as the immediate relief of tension in a

swollen limb by incision of the deep fascia removes a serious brake on the circulation, besides giving a good exit for any pent-up gas or fluid.

It may be that the swelling is the result of hæmorrhage into the limb; the position of the wound will give a good indication which vessel has been wounded. Any damaged vessel should be immediately ligatured as it lies in the wound—*i.e.*, at the site of injury. Under exceptional circumstances only, which will be referred to later on, should a large vessel be ligatured in its continuity, for such treatment invariably ends in disaster. It is hardly necessary to mention that a damaged vessel should be ligatured both above and below the breach in its wall, and if the damaged vessel be an artery, it is advisable to ligature the accompanying vein at the same level.

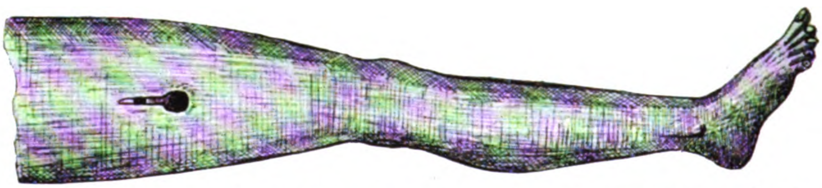


FIG. 78.—Seton wound after excision and prolonging incision to expose the perforation in the deep fascia.

After excising the wounds and making any further necessary incisions to relieve tension, a long pair of Spencer Wells forceps is carefully introduced into the inlet hole in the deep fascia, and the points are made to emerge at the exit hole. A strip of sterile gauze soaked in hydrogen peroxide is then drawn along the track of the wound through the soft parts once or twice. By this means any small pieces of clothing are removed from the track of the wound, together with any débris in the form of dead tissue.

B. **Penetrating Wounds.**—All skin for a distance of a quarter of an inch from the wound, or more if necessary, should be cleanly excised, together with the subcutaneous tissues and deep fascia. Incisions should now be made from the excised wound, with a clean knife, in either direction. The finger is then gently inserted into the wound through the deep fascia, and is made to travel along the breach produced in the muscles and soft parts. No force should be exercised while inserting the finger, as it is extremely easy to make false tracks in the damaged tissue, and when once this is done the hunt for the missile usually ends in disappointment.

A certain amount of practice and experience is needed in order to follow successfully with the finger the track of a missile in damaged tissue, but with patience and perseverance the knack is soon acquired, and the surgeon knows almost instinctively whether or not his finger is going in the right direction.

The sense of touch in wounds is very important to develop, and

the feel of the track of a missile is both familiar and characteristic to a surgeon who has had experience at a casualty clearing station. The important point, let it be repeated, is to use no force at all in introducing the finger; far rather let the finger find its own way than the surgeon find a way for it.

When once the missile, with its concomitant piece of clothing, has been found and removed, the surgeon can now deal with the damaged tissues. It must not be forgotten that it is just as, if not more, important to remove the piece of clothing from the wound as it is to remove the metallic missile. As a rule the clothing is usually adherent to the missile, but this is not always the case, for on many occasions clothing and other foreign bodies have been found in the tissues independent of the missile. At the casualty clearing stations such articles as coins, pieces of pencil, matches, remnants of letters, and in one case a portion of a miniature New Testament, have been extracted from various wounds. Surgeons should always anticipate the presence of these foreign bodies when dealing with wounds in which the missile has traversed the region of one of the soldier's pockets. It was a rule to lecture all N.C.O.'s and men on the inadvisability of carrying unnecessary articles in their pockets while in trenches or during an attack.

When wounds have been fully opened up it is often surprising to find the amount of damage sustained by the soft parts. There is usually present a quantity of foul-smelling, dark-coloured discharge, and not infrequently the divided ends of the muscles and the deeper structures lining the wound are covered with a greyish diphtheroid membrane, or the muscles and soft parts may present a dark-coloured, dry, and lifeless appearance. In the former case an organism commonly present is Vincent's bacillus, whereas in the latter the usual combination met with is that of *Streptococcus fæcalis* and *B. perfringens*.

All infected tissue must be completely excised, and this is best accomplished by means of stout, sharp scissors.

Wounded and stunned tissue when cut does not bleed; and if it be muscle, it does not contract. Excision should continue until healthy bleeding contractile tissue is reached, and the surgeon must not stop until he has accomplished this, because every piece of dead and stinking material he leaves behind in the wound is further pabulum for the organisms of infection.

When excision of all dead skin, muscle, bone, and other structures is complete, it is very important to secure absolute hæmostasis. Any blood-clot left in wounds forms very favourable pabulum for organisms left behind to luxuriate in.

After complete exploration and excision the wound is stitched widely open with silkworm-gut sutures, to allow of suitable and adequate application of the antiseptic.

A safe rule is, if in doubt, err rather on the side of doing too much

than too little when excising a wound, and freely prolong incisions into distant œdematous tissue. It is only after considerable experience and practice that a surgeon learns exactly how far to go, and until this experience is acquired it is the lesser evil to err, within limits, on the side of doing too much.

C. **Large Lacerated Wounds.**—Here most of the damage done is apparent and not latent, as in penetrating wounds. The treatment is complete excision of all dead skin and devitalised tissue, procuring at the same time absolute hæmostasis, just as was done in penetrating wounds. This class of wound is, as a rule, freely laid open by the missile, hence it will not in the majority of cases require sutures to keep it patent, as in the case of penetrating wounds.

D. **Multiple Wounds, usually the Result of Hand Grenades.**—Such wounds are practically always of the penetrating variety, and are small. The immediate treatment called for is not so much for the wounds themselves, as for the shock occasioned by them. This class of wound may be divided into two groups as follows:

(1) Numerous multiple wounds. The wounds, as a rule, are not deep and are more the result of dirt and very small fragments of thin metal. They result from one of the high-explosive hand grenades used by the Germans (see Chapter I.).

(2) Multiple wounds, not so numerous as in the former variety, but in which the fragments have penetrated deeper into the tissues, and these result from a different type of hand grenade, which is charged with metallic débris in the form of broken nails, screws, broken bolts, and the like (see Chapter I.).

Bomb wounds now form a very considerable percentage of the present war wounds; they are of a serious nature, and call for special consideration. Shock is especially pronounced, and it is well before operating to get the wounded man thoroughly warm in bed and to administer, if possible, a subcutaneous saline. Wounds coming under Class 1, in addition to containing many small pieces of dirt, practically always show a degree of scorching. They are most commonly met with about the exposed parts of the body, such as the face and hands, but in a number of instances large pieces of the soldier's clothing have been torn off, and his whole back may present a superficially riddled appearance, or the legs and thighs or buttocks may be affected.

The whole part should be most thoroughly cleaned by scrubbing with hydrogen peroxide after the surrounding skin has been prepared. Hydrogen peroxide cleans this class of wound better than anything else. After thorough cleaning with this antiseptic, the whole wounded area is dried, and scored with the point of a scalpel or sharp cutting needle. This done, a salt pack is applied to the whole surface. In the case of the face the best dressing is hypertonic saline.

If the skin in addition be badly scorched, after treatment with per-

oxide and scoring, the wound is washed with sterile saline, carefully dried, and dressed with paraffin No. 7. With the salt pack these multiple superficial wounds have progressed rapidly and satisfactorily ; the patients seem comfortable and complain of little pain.

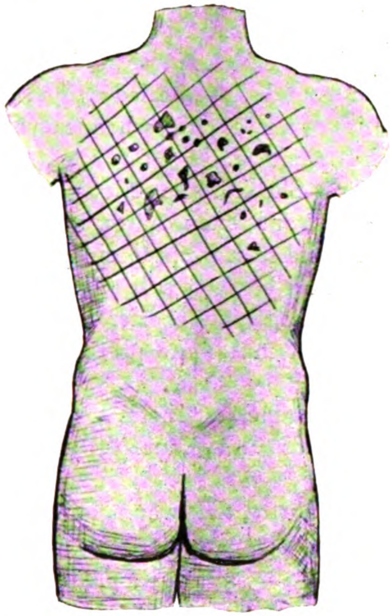


FIG. 79.—Multiple bomb wounds of back.
Scoring of back prior to application of salt pack.

In the second variety of multiple bomb wounds, if the missile be large, it must be removed after excision of the wound. Usually multiple wounds from this cause are all small, there is but little swelling around them, and the patients on the whole do infinitely better if left alone for two or three days, provided important parts, such as the head, abdomen, and the larger joints, have not been penetrated. Shock at this stage is the main condition that calls for treatment. It is quite soon enough if the operation for the removal of these foreign bodies be undertaken at the base hospitals, about the fifth day after injury. At the end of the fifth day it is usually evident which of the remaining foreign bodies are going to give rise to trouble. The plan we have adopted with this class of case at the base hospital is to squeeze gently round the wound, which appears to be inflamed. Those from which a purulent discharge emerges are dealt with ; the track can be easily followed and the foreign body removed. The patient himself is the surgeon's best guide. He will pick out the wounds which at this stage have become painful, and the wounds he picks out are invariably those which require surgical treatment. A number of the wounds heal without any further trouble ; hence it is always best

to wait and see which require treatment and which do not, before making a bold attempt to remove all the foreign bodies at one sitting, a procedure which jeopardises the patient's chances of recovery much more than waiting.

We feel completely justified in offering this advice, as we have seen the results of both early and late treatment in a large number of these cases, and can definitely say that the plan of waiting is in every way advisable.

Cases in which the wounds have healed with the foreign body still in can always be dealt with at a later date, when the patient is in a far better condition to stand the operation.

Treatment of Shock.—Shock is the serious complication of all severe wounds. It may result from reflex causes, such as is seen in multiple wounds or severe compound fractures, especially of the femur; from large lacerated wounds, or it may be the result of severe primary hæmorrhage. Reflex causes and hæmorrhage may coexist, giving rise, as before stated, to intensified shock, which makes the prognosis in any particular case much more grave.

Transport does much to increase shock, especially in the case of penetrating abdominal wounds and imperfectly immobilised compound fractures.

It should never be forgotten that wounds are usually inflicted on men who are already suffering from fatigue, and that very soon after their infliction virulent organisms which have gained entrance into the wound begin to exert their toxic action. Hence, superimposed on shock there is a degree of fatigue and toxæmia to be reckoned with.

Psychic shock has also to be considered, as it is present in a large number of men, especially officers. Horror at some sight they have seen, such as the mutilation of a comrade, the fact that a large proportion of their regiment has been wiped out, and the like, are sufficient to produce psychic shock of an advanced degree.

Wounded men arriving at a casualty clearing station suffering from severe shock, with the accompanying conditions of fatigue and toxæmia, must be put in bed, well warmed, given normal saline with sodium bicarbonate subcutaneously or intravenously, and not taken direct to the operating-theatre, unless immediate operation is indicated for such reasons as hæmorrhage or advanced gas gangrene of a limb. Stimulants may be given by mouth, and hot drinks if the patient is not vomiting. Pituitrin administered hypodermically along with the saline is a valuable asset. If after three or four hours the pulse has improved, the patient can be taken to the theatre, if this is necessary.

The operating-table should be warmed, and if a heating apparatus is not provided with the operating-table, hot-water bottles should be substituted, but great care must be taken not to burn the patient.

During the operation, which should for serious cases be performed under ether, preferably given by the endo-tracheal method in combination

with oxygen, saline and bicarbonate should be slowly administered all the time subcutaneously or intravenously, and with it brandy or pituitrin. The operation should be performed as rapidly as possible consistent with efficiency. Hæmostasis should be procured throughout the operation, for at this stage the patient can ill afford to lose any blood. The dressing should be applied, and the wounded man returned to a warmed bed with the foot raised. As soon as he has recovered from the anæsthetic, provided he is not vomiting, hot stimulating drinks should be given, and additional saline *per rectum* if necessary. This latter part of the treatment is often impossible, as so many wounded men are profoundly constipated, and the rectum is usually full of hard fæces.

Often after returning to bed from the theatre the patient breaks out into a copious perspiration, and with this there is a rise of temperature and a more rapid though improved condition of the pulse. This is a good sign, as toxic bodies from the tissues are being eliminated by the skin, and the patient is reacting to treatment.

As soon as possible after operation an aperient, aided, as is usually necessary, by an oil and turpentine enema, can be given.

As early as possible the patient may be given solid food, and it is often amazing to hear severely wounded men, who have suffered considerable shock, ask for meat and potatoes on the day following an operation. This should never be withheld, for often one man's meat is another man's poison, and a man's stomach is its own best judge under such circumstances as these.

Saline with sodium bicarbonate administered early hypodermically or intravenously has, whatever the critics say, clinically proved itself of the utmost value to men who have been severely wounded, and who are in addition suffering from shock, hæmorrhage, fatigue, and toxæmia. Not only does it replace temporarily the fluid that is lost, but it also washes the tissues of the products of fatigue and bacterial toxins. It is also highly probable that the addition of sodium bicarbonate to the saline brings about the good effect that it undoubtedly does by neutralising the acid products of fatigue, and so helping the wounded man's natural resistance. We can, after an extensive trial, strongly recommend its use.

We feel that we cannot too strongly emphasise the fact that the surgical treatment of a wound, though highly important, is only a part of a necessary routine procedure. Equally important is the treatment of the wounded man's general condition, for, after all, it is his own defensive forces that have to carry on the battle against shock, fatigue, and infection after the surgeon has treated his wound, and it is the surgeon's duty to help his body resources in every possible way. He must be put under the best conditions possible to battle against the formidable foe of infection, and although we cannot hope to simulate Nature's work, yet we can aid and to some extent direct it.

Dressing the Wound.—After a wound has been surgically prepared, the question of the dressing remains for consideration, and this brings us to the subject of antiseptics. Here we must again look back and reflect for a brief period on the history of antiseptics during the present war, and recall our treatment of wounds in civilian practice.

In civilian practice wounds are treated very soon after their infliction. In the casualty department of one of the big London hospitals the two cardinal principles of wound treatment—viz., the prevention of further infection and the eradication of any existing infection—were always most conscientiously carried out on Listerian lines. The skin was thoroughly cleaned and shaved around the wound, the wound itself was thoroughly cleansed with Lister's strong mixture after cutting away any obviously dead tissue, and dressings of 1 in 2,000 perchloride of mercury were applied. Smaller wounds after this treatment were sutured, and on the whole healed well. Wounds involving bone were swabbed out with pure carbolic acid, and afterwards washed out with a 1 in 2,000 solution of perchloride of mercury, this treatment giving highly satisfactory results and often resulting in healing by primary union. This, however, was not the case, in regard to wounds of the present war, because here there is an entirely different type of wound to deal with. Wounds treated by pre-war antiseptics have turned out disastrously, because the older antiseptics fail to fulfil the conditions of an ideal antiseptic.

What, then, is an ideal antiseptic? An ideal antiseptic must possess the following properties:

(1) It must be a highly potent bactericide.
(2) It must be innocuous to sound tissue, but must rapidly remove dead tissue and sloughs.
(3) It must be non-poisonous to the individual when applied in large quantities to an extensive wound.
(4) It must be innocuous to leucocytes and not delay their functions.
(5) It must act in the presence of serum or wound exudate.
(6) It must not delay, but rather hasten, tissue repair.
(7) It must be an antiseptic which will help the patient for the first few days following his injury, and not rely upon the patient helping himself.
(8) It should be cheap and must be easily prepared.

It will at a glance be seen that none of the older antiseptics fulfil these eight conditions. Carbolic acid is poisonous to the individual and also to the leucocytes, whereas perchloride of mercury is not only poisonous to the individual and the leucocytes, but its action as an antiseptic is soon nullified in the presence of serum, as it rapidly forms albuminates. Further, the dilution in which these antiseptics must be applied to the present war wounds renders them as rapid bactericides quite inefficient.

Earlier in the war irrigation of wounds, either continuous or intermittent, with various antiseptics was freely practised. Carbolic acid, a mixture of carbolic acid and hydrogen peroxide, various strengths of potassium permanganate, and the like, were tried and advocated by different surgeons. Better results were claimed in wounds treated with certain antiseptics than in wounds treated with others; in brief, the whole question of antiseptics and their mode of application to gunshot wounds was indefinite and inconsistent.

Wright and Gray then introduced the salt treatment, and though results were better than anything hitherto seen, the salt treatment for early wounds failed in the following important details:

(1) Hypertonic saline or salt packs do not promote, but actually impede, diapedesis of the leucocytes.
(2) Hypertonic salt solution possesses very low bactericidal powers.
(3) It is a treatment which does not help the individual throughout the period immediately following the infliction of a wound, but relies rather on his own natural power of resistance.
(4) Hypertonic saline withdraws serum from the body at a time when it is not only inefficient to combat infection, but also at a time when the wounded man can ill afford its loss.

Wounds undergoing treatment with the salt pack were often extremely offensive, though the temperature and pulse were satisfactory. This in itself in the hot weather, especially in the Eastern theatre, was sufficient to attract a large number of flies to the ward, and was therefore not only undesirable, but dangerous.

Salt treatment applied early after excision of a wound relied upon the wounded man assisting himself with his own blood-serum, which in fatigued, shocked, and completely knocked-out men was useless. Hence at this stage in the history of wound treatment it was better suited for men who had materially recovered as far as their general condition was concerned. The inadvisability of the salt treatment for seriously wounded men in the period immediately following infliction of their wounds, when their natural resistance was low, was known to many who were working at the casualty clearing stations. Irrigation by normal saline solution did good locally by washing away toxins and sloughs as they separated, and it probably washed away many bacteria. It did good in that it encouraged rather than prohibited the emigration of leucocytes into the wound, but it failed in that it is not a bactericide, but rather, in the presence of wound exudates and serum, it enhances the growth and proliferation of bacteria. It further tends to make the tissues sodden, and so delays tissue repair.

At this stage there was no recognised standard method of wound treatment; in fact, many surgeons were going their own way, and but little

advance towards a sound, rapid, and efficient method of treating wounds was being made.

A certain Cabinet Minister, while visiting France and the various British hospitals there, made the observation that it seemed to him curious that one hospital was adopting one method of treatment while another hospital was adopting another. In fact, he said, "Why can't you all meet and decide on one satisfactory method of treating wounds?" or words to this effect. There is little doubt that a satisfactorily standardised method of treating wounds would save many lives and limbs, would be of the greatest help in the organisation and administration of the medical services, and would save the State considerable expense.

The Carrel-Dakin Treatment of Wounds.—After considerable experience in all medical units from firing-line to base, the authors are firmly convinced that the Carrel-Dakin treatment of wounds is so far the most satisfactory. Out of nearly 2,000 consecutive cases treated at a base hospital by this method, the results have not only been the quickest and the best, but also the cheapest and most economical to the State.

The treatment consists in the regular intermittent watering of a surgically prepared wound surface with an ideal antiseptic—that is, an antiseptic which as nearly as possible fulfils the eight conditions already enumerated. Carrel and Dakin used the hypochlorites as their antiseptic, the one selected being the Daufresne modification of Dakin's solution (available chlorine ·22 per cent.). The treatment practically amounts to dressing a surgically prepared wound hourly or two-hourly with an ideal antiseptic.

The method of surgically preparing a wound has already been described, but it must be remembered that a surgically prepared wound, however thorough the excision, is not bacteriologically sterile. As far as possible all pabulum for bacteria has been removed, and the wound put under the best conditions for rapid sterilisation. It is of the greatest importance that the wound be excised at the earliest possible moment after injury, for the earlier excision is undertaken the more rapid and simple becomes the subsequent sterilisation, and *vice versa*.

The hypochlorites, when applied on a gauze dressing, rapidly lose their bactericidal properties and become quite inefficient at the end of an hour. If the dressings had to be changed hourly, this would cause much extra work, much pain to the patient, and would interfere with wound rest. Carrel overcame these difficulties by the introduction of his tubes.

Method of applying a Carrel-Dakin Dressing.—After the wound has been excised, sterile carbolised vaselin spread out on sterile butter muslin is first laid on the skin around the wound. This preliminary dressing should come to within a quarter of an inch of the wound edge.

If the wound be a deep one and contain recesses, its walls should be kept apart and its recesses kept open by some device such as sterile struts made

from pieces of stout rubber tubing or pieces of metal. We have found it a far more satisfactory method to stitch the wounds widely open by means of stout fishing gut. It may be necessary in some cases to use a combination of the two. Over the vaselin dressing is placed sterile gauze wrung

FIG. 80.—Large wound of thigh stitched open after excision.

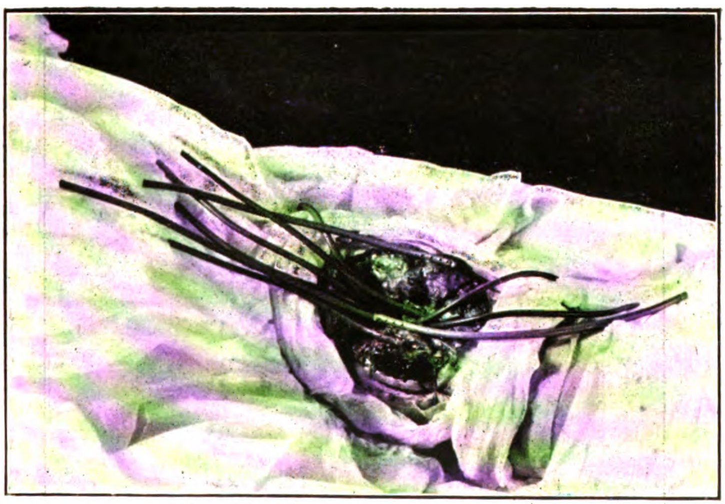


FIG. 81.—The same wound of thigh with Carrel's tubes inserted after the application o sterilised vaselin and gauze to the surrounding skin.

out of hypochlorite solution. This layer of gauze should be about a quarter of an inch in thickness. Carrel's tubes are now laid in the wound, and these must be arranged in such a way that every part of the wound, especially the recesses, gets its share of antiseptic hourly. The tubes are kept in position by means of gauze. After the tubes have been suitably

placed, small rolls of gauze wrung out of hypochlorite solution pass from one side of the wound to the other, and rest on the gauze which has been placed over the carbolised vaselin.

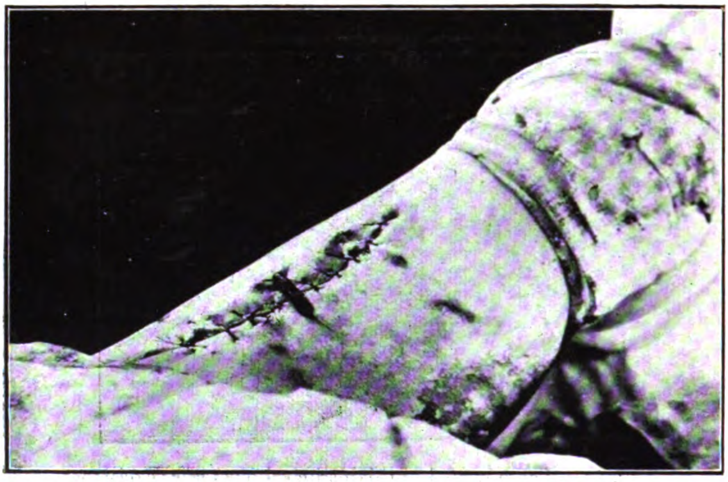


FIG. 82.—The same wound sutured after sterilisation.
Wound healed *per primam.*

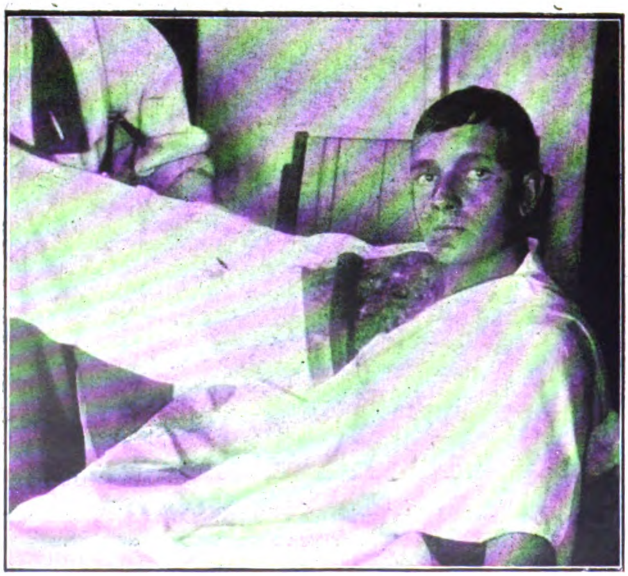


FIG. 83.—Large gangrenous wound of the shoulder-joint involving a compound fracture of the upper end of the humerus.

Over the rolls of gauze which bridge across the wound is laid a gauze dressing. It will thus be seen that the wound has been converted into a virtual box or sump, and the gauze dressing placed over all constitutes the

lid. It will also be seen that no gauze touches the wounded surface; hence the changing of these dressings is an absolutely painless procedure.

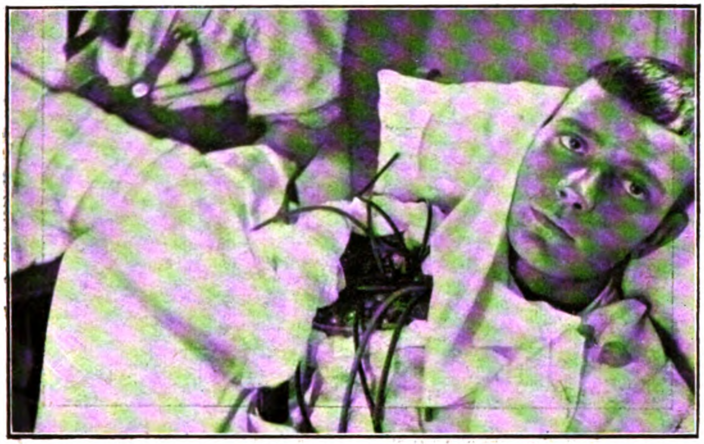


FIG. 84.—Same wound with a Carrel-Dakin dressing applied.

Over all is now placed the final part of the dressing, and this consists of wool, old bandages, and other resterilised and absorbent material included between two single layers of gauze, resembling gamgee tissue.

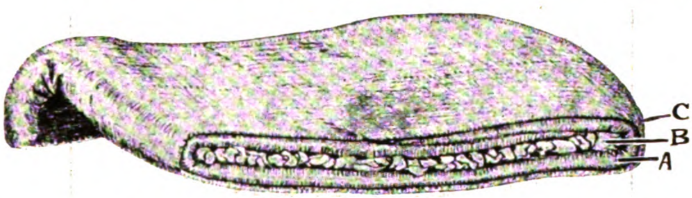


FIG. 85.—Gamgee tissue made from old wool and ends of used bandages that have been resterilised.

A, resterilised wool that has already been in use; B, cut-up pieces of used bandages; C, single layer of cyanide gauze.

This final part of the dressing completely surrounds the limb or other wounded part, and is fastened by safety-pins.

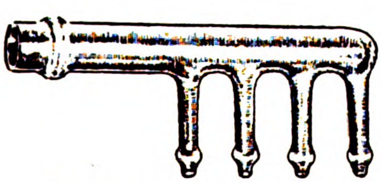


FIG. 86.—Four-way glass piece.

The tubes emerge through holes cut in the gamgee tissue, and their ends are attached to four-way glass pieces. We have employed as few as

four and as many as twenty tubes for wounds of different dimensions. In large wounds it is better to err on the side of using too many than too few.

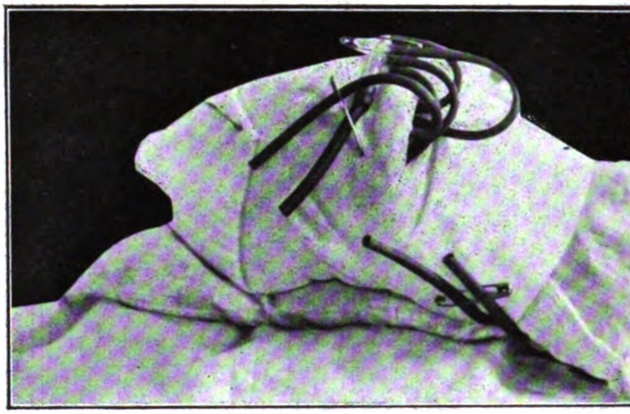


FIG. 87.—Wrong method of leaving Carrel's tubes.
Note that the open ends occupy a dependent position.

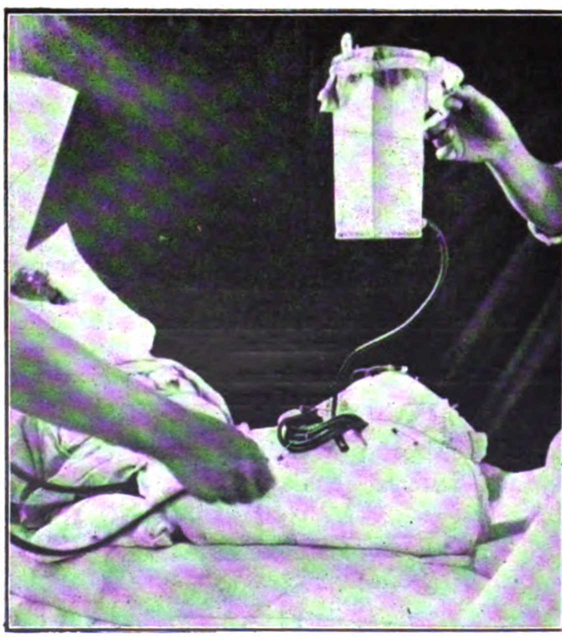


FIG. 88.—Correct method of leaving Carrel's tubes.
Note that the tubes and their open ends occupy a position above the level of the wound.

One or two drachms of the antiseptic per tube are instilled hourly, and the dressing is preferably changed daily. In cases of emergency a dressing may be left for forty-eight or seventy-two hours, and out of a very large number

of wounds we have seen no harm result from this practice, though a daily dressing, if possible, is preferable.

There is much to be learned with regard to the successful application of a Carrel-Dakin dressing, and no surgeon, however skilled, can grasp all there is to be known about the Carrel-Dakin method in a day or two. There are many pitfalls, not only during the subsequent treatment, but also in the application of the original dressing ; hence it is only after two or three months' experience that a surgeon can become *au fait* with Carrel's method of wound treatment. To arrange Carrel's tubes adequately in different wounds, such as dependent wounds of limbs, wounds of the face and jaws, wounds of the buttock, back, and the like, in such a way that they will act efficiently, and to arrange a convenient and comfortable posture for the patient during the few days of sterilisation, calls for considerable ingenuity and affords scope for originality and suggestion. Each day a surgeon discovers some new and original piece of apparatus which is an improvement on what he was using before, and each day he learns something new.

After the dressing has been applied it should be ascertained that all the tubes are working efficiently, and that none of them are kinked.

The ends of the tubes must never be allowed to occupy a dependent position, but must be above the level of the wound. If this be not the case, the antiseptic will siphon back immediately after being instilled, the wound will not get its proper supply of antiseptic, the bed becomes wet, and the patient's skin becomes sore.

The practice of leaving the ends of the tubes in a dependent position is an extremely common fault, and should never be allowed to happen.

CHAPTER XV

GENERAL TREATMENT OF GUNSHOT WOUNDS (*Continued*).

Treatment on Lines of Communication and at the Base Hospital.

As soon as the patient's condition permits, he is sent to a base hospital. Hourly or two-hourly instillation with the antiseptic is carried out on the hospital train, and this is continued at the base hospital until the dressing is changed.

It is very important to realise that when once a wound is surgically prepared and the first dressing applied it is then a wound undergoing a process of continuous sterilisation ; hence at each subsequent dressing the very strictest aseptic precautions must be practised, and as much attention paid to one of these wounds as would be given to a clean abdominal incision or a clean incision opening the knee-joint, because surgically prepared wounds are most easily reinfected through any small error in technique.

This cannot be too strongly emphasised, for it is inattention to what appear to be trivial details that has so often brought about failure, and caused the Carrel-Dakin treatment to be unfairly criticised. We are convinced that wherever failure occurs it is not the treatment that is at fault, but the way in which it has been carried out.

Application of Tubes.—A very important precaution in the Carrel-Dakin system of sterilising wounds is to see that every part of a wound, especially its diverticula, receive a constant and regular supply of antiseptic. This means that the arrangement of the tubes in the wound must be both accurate and efficient.

In what might be called a sump wound the process is simple, and one tube will suffice (see Fig. 89).

In more superficial wounds of considerable extent, we have adopted the plan of converting these wounds by artificial means into sump wounds by the use of gauze (see Fig. 90), and have obtained excellent results.

For sloping wounds the Carrel's tubes must be laid at the highest point of the wound, so that the antiseptic runs down periodically over the whole wound surface. Tubes applied halfway down or at the bottom of such wounds are useless (see Fig. 91).

In dependent wounds the tubes must be kept in contact with the wound

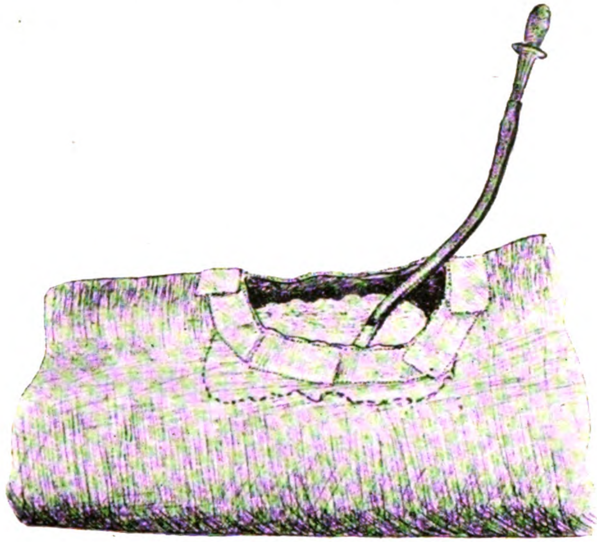


FIG. 89.—Sump wound.

The dotted line shows the depth of the wound. The skin around the wound edge is protected with carbolised vaselin. One tube is inserted and the sump is kept filled with the antiseptic until it is sterile and ready for suture.

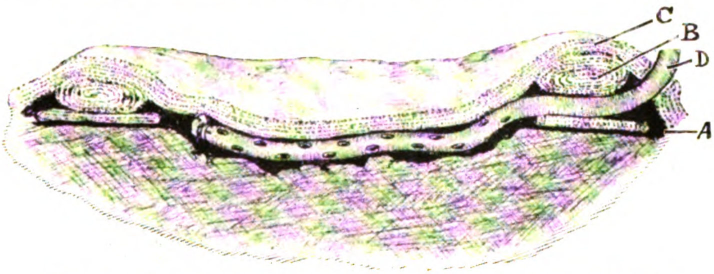


FIG. 90.—Large superficial wound converted into a sump wound.

A, carbolised vaselin ; B, gauze ; C, outer dressing ; D, Carrel's tube.

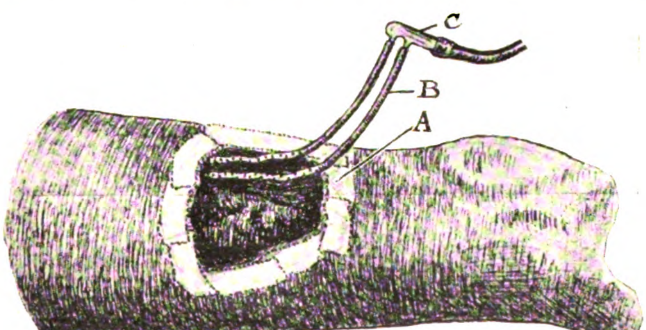


FIG. 91.—Sloping wound on outer aspect of thigh.

A, carbolised vaselin ; B, Carrel's tubes placed at highest aspect of wound ; C, two-way glass piece.

surface by some suitable device. The method we have employed has been that of strips of sterilised gauze passed around the limb, securing part of

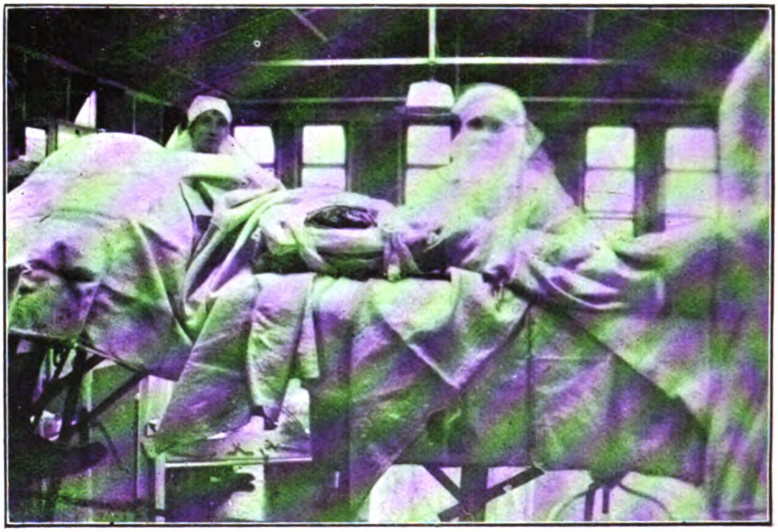


FIG. 92.—Large wound of thigh converted into a sump wound prior to insertion of Carrel's tubes.

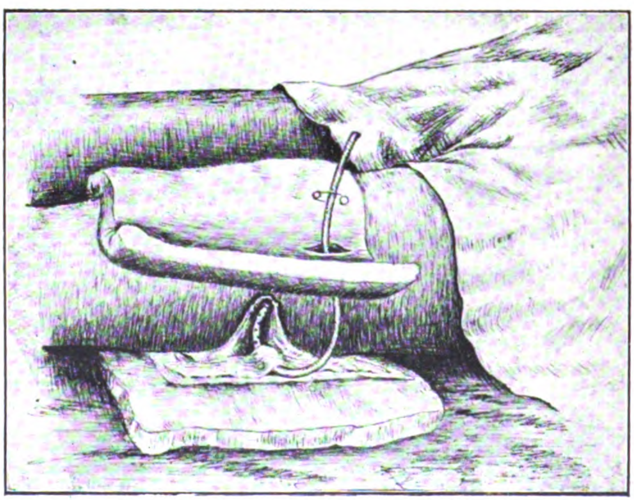


FIG. 93.—Dependent wound of thigh seen in section.
The wound is lined by a single layer of gauze, and a Carrel's tube inserted.

the dressing and the tubes. Over this the final dressing is fixed. This has given excellent results, equal to those obtained in wounds in other situations.

Seton wounds which require it, can be sterilised by placing a Carrel's tube along the entire track.

Carrel has recommended in the case of dependent wounds, providing they be deep and not of great extent, that a petticoated tube be employed, bath towelling being used for the petticoat. We have tried this method, but have obtained far better results by lining accurately such a cavity with a single layer of gauze, and inserting one or two Carrel's tubes.

It is quite useless to insert a Carrel's tube into a small punctured wound. The antiseptic is forced into such a wound under pressure, and it can neither circulate nor escape. The wound must be sufficiently enlarged before such a process of sterilisation can be properly carried out.

In all wounds except the deep dependent wounds there should be no dressing between the tube and the wound surface. If possible, it is pre-

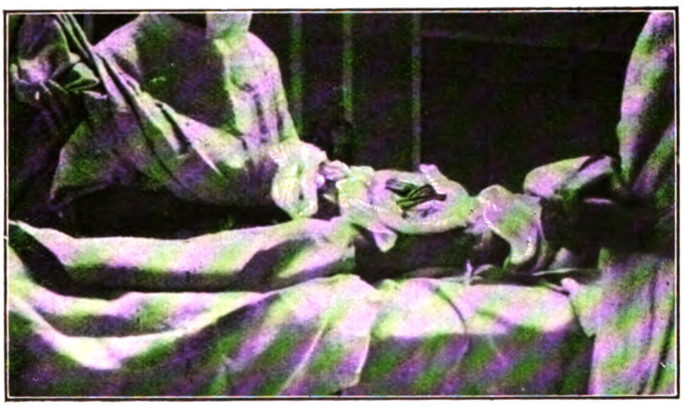


FIG. 94.—Wound of thigh converted into a sump wound and Carrel's tubes inserted.

ferable that the tube should not touch the wound surface, owing to the risk of blocking the holes.

For sterilisation of wounds of the back and buttock the patient must be nursed on his side. Thus, if the right back or right buttock be wounded, he must lie on his left side.

It is impossible to put into writing the very many points to be observed and carried out in the Carrel-Dakin treatment of different wounds ; it is by experience only that a surgeon becomes *au fait* with them. The treatment invites both ingenuity and originality, and our experience goes to show that endless diagrams and hints in print will not materially help a surgeon. The following general principles will be of help :

1. Surgically prepare the wound by excision at the earliest possible moment after the wound has been received, *and procure absolute hæmostasis.*

2. Apply the tubes in such a way that every part of the wound receives

an adequate and efficient periodic supply of the antiseptic, and do not, except in the case of deep dependent wounds, put any dressing between the wound surface and the tubes.

3. If necessary—and it is usually so in the case of large, deep wounds—fix the wound completely open to the fullest extent of its depth with silk-worm-gut sutures before putting in the tubes.

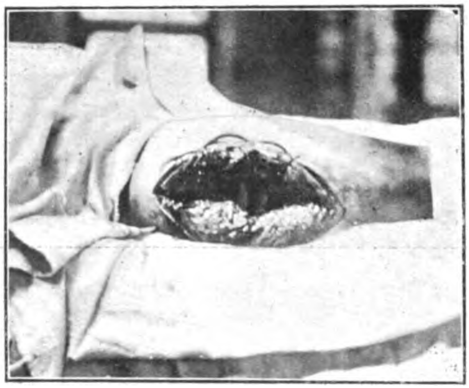


FIG. 95.—Large wound of thigh involving a compound comminuted fracture of the femur stitched widely open prior to application of Carrel's tubes.

Two large rubber tubes have been inserted in the depth of the wound to keep open the diverticula.

4. Keep open by plugs of gauze or stout rubber tubing every diverticulum.

5. Be sure that every tube is working and not kinked after the final dressing is applied.

6. Be sure that the open ends of the tubes do not occupy a dependent position ; for if this be the case, the antiseptic after instillation will simply siphon back into the bed, wet the sheets, and give the patient a sore back. This is a particularly common fault, and we draw special attention to it.

7. In the case of severe comminution of bone, be sure that the tubes go down to and in among the fragments. A tube laid into the wound and not reaching the fracture is useless.

8. Never leave a tube in contact with a large artery, vein, or nerve.

9. If there be a sinus going down to the bone, or a sinus in the tissues at the bottom of the wound, leave the end of the tube at the bottom of the sinus open.

10. Do not expect rapid sterilisation of a compound comminuted fracture of a long bone, but persevere with the Carrel-Dakin treatment. In some rare cases it has taken us as long as five to six weeks to effect sterilisation, whereas in the majority of cases it has taken twelve to fifteen days. In a few cases sterilisation was complete in four to six days, and these latter occurrences are daily becoming more frequent with increased experience.

11. Never give up hope in cases of injury to the tarsus and metatarsus. These wounds are notoriously difficult of sterilisation, owing to the intricate nature of the synovial sacs. Perseverance will bring about sterilisation, even though it be long delayed (five to seven weeks), and serviceable feet have resulted which but a year ago would have been doomed to amputation.

12. Do not be disappointed with early or even late failures. Wherever this has occurred, it has been found, after very thorough inquiry, that it was not the method that was at fault, but the way in which it had been carried out.

13. Always remember that wounds, when once under treatment, are wounds undergoing sterilisation. Subsequent dressings must be carried out with every aseptic precaution, gloves, cap, sterilised gown and sterilised towels being used. The wound should not be touched with the gloved hand, but only with boiled instruments. All medical officers should be dressed and scrubbed up in exactly the same way as they would be if assisting at a clean operation. Scrupulous cleanliness and asepsis must be exercised in the dressing of all wounds. This technique, laborious as it may seem, has given the best results in a series of over 2,000 consecutive cases of serious gunshot wounds treated in this hospital from start to finish.

Practical Considerations relating to the Carrel-Dakin System of Treatment of Wounds.

Apart from the immediate dangers of infection, the most serious complication of the modern gunshot wound with which the surgeon has to deal is the formation of an excessive amount of fibrous tissue (which constitutes great scars). Excessive fibrous tissue is the tombstone of a prolonged infection. The longer a wound discharges, the greater is the amount of fibrous tissue formed ; and such excessive scarring is seen only too commonly in wounds to-day, both small and large, which have been allowed to heal by the slow process of granulation.

A large proportion of the disability following wounds is due to the presence of fibrous tissue, not only in the wound itself, but in such important structures as muscle and nerve which lie in its immediate neighbourhood. Disability from this cause is not only mechanical, and due to stiffness resulting from the welding together of muscles, nerves, and other structures, in one dense mass, but much disability is brought about by pain, often of a most intolerable character, owing to the inclusion of sensory nerves in the scar tissue. It is therefore obvious that if gunshot wounds can be rendered sufficiently free from bacteria to permit of their closure by suture within a reasonably short period after their infliction, the result will resemble that of a clean operation wound, and excessive scar tissue with its accompanying disadvantages will be avoided.

The modern gunshot wound is characterised by the excessive amount of damage wrought in the tissues, not only in those of the parts of the wound

which are apparent (manifest trauma), but also in the tissues of the parts distant from the wound (latent trauma). The damaged and dead tissues form excellent pabulum for the growth of the germs of infection. Hence, if these germs be given a chance they will not only flourish in the wound itself, but will extend into the latently damaged tissue at some distance from the wound. The first step in wound treatment, then, should aim at the removal of the missile, its concomitant piece of clothing, and the dead and seriously damaged tissue, so that as little pabulum as possible suitable for the growth and multiplication of wound bacteria is left behind. This is accomplished by complete excision of the wound as soon after its infliction as is possible—that is, before infection has become firmly established. Excision of the wound, however skilfully performed, does not leave the resulting wound absolutely germ-free. There is always some residual infection, and this can be overcome by the use of antiseptics.

The antiseptic used should be non-poisonous to the individual generally and to his tissues locally ; it must not materially hinder the action of the leucocytes ; its bactericidal properties must not be impaired to any extent by the presence of the wound discharges ; it should be highly bactericidal, and should be capable of penetrating the tissues to some degree. Hypochlorous acid fulfils all these requirements. At the end of an hour this antiseptic, if applied on a gauze-dressing, becomes used up and requires renewing—a process which would entail a quite impracticable amount of work on the part of the staff, and of distress on the part of the patient. Carrel overcame this difficulty by the introduction of his finely perforated tubes. By means of these tubes, the wound is sprayed hourly with a solution of this antiseptic. The tubes are changed daily or every second day and the wound discharge is examined by a bacteriologist. Gradually the bacterial count of the wound diminishes, and when the bacteriologist reports an average of not more than two organisms to five fields of the microscope (0·4 organism per field), a stage which may be reached in most cases from the fourth to the twelfth day following the infliction of the wound, then the wound may be safely closed. By this means the formation of fibrous tissue is reduced to a minimum, and the sutured wounds resemble in every detail wounds that have healed by primary union.

The Carrel-Dakin system has as its object the closure of a wound at the earliest possible moment after its infliction, thus causing the minimum of disability from the excessive formation of fibrous tissue, the minimum of pain resulting from scars, and the possibility of the maximum benefit being derived from any orthopædic treatment which may be instituted at a later date.

Modifications of Carrel's method have been advocated by other surgeons. Thus, after excision of the wound, different antiseptic pastes have been smeared over the newly prepared surface in order to deal with the residual infection, and the wound has been closed forthwith (primary suture). Though some brilliant results have been reported the method

is hazardous, for it depends upon how thoroughly the excision of the wound has been performed—that is, it relies upon the experience of the surgeon. The Carrel-Dakin method is safer, and gives equally good results.

The early closure of wounds makes for economy in every direction—to the individual, to the army, and to the State. To the individual it has meant the saving of life and limb in many hundreds of instances; it has meant the prevention of permanent disability, and, in many cases, of any disability at all; and it has prevented untold pain and suffering, for even the most ghastly of wounds can be treated painlessly from start to finish by this method. The Carrel-Dakin scheme, if properly carried out, is essentially a painless one, and patients have actually slept while such extensive dressings as those required for compound fractures of the femur have been carried out. From the point of view of army economy, the fact that many cases, including those of severe compound fracture of bone, have been returned to duty without leaving the country is sufficient evidence of the practical efficacy of the treatment. From the point of view of the State, expenditure has been saved in many directions; human life has been conserved; expenditure on pensions has been consequently diminished; and, in addition, the expense of treatment of our wounded has been very materially cut down. For example, in one particular series of 1,000 seriously wounded men the expenditure on surgical dressings worked out at the low average figure of 7s. per head from the beginning to the end of treatment.

The Carrel-Dakin treatment is one which can be standardised and carried on continuously between field ambulance and base. This has been found to be possible and practicable in the Balkans, where the question of transport is a very different problem from that which obtains in the Western theatre of war.

In carrying out the treatment, correct technique is absolutely essential, and it is failure to achieve this which has led to adverse criticism of the method on the part of certain sections of the medical profession, and has also given rise to the suggestion of various unsatisfactory modifications. Medical officers unfamiliar with the treatment must be prepared to spend at least two months in mastering the many and varied details of technique, attention to which alone can yield the astonishingly good results which have actually and uniformly been obtained.

Close co-operation between surgeon and bacteriologist is absolutely essential to success. No surgeon, whatever his experience, can tell by clinical observation when a wound is ready for secondary suture. Moreover, every surgeon should be accurately informed of the type and degree of infection present in the wounds with which he is dealing, in order that he may be assured that his technique is correct. For instance, if the bacterial count of a wound suddenly increases, he knows that either the antiseptic is deficient or his technique is at fault, and this may occur although the wound appears clinically satisfactory.

What are the Advantages of the Carrel-Dakin Treatment?

1. It is a treatment which relies less than any other on the wounded man's own recuperative powers for the first few days.

2. It is at present the most rapid method we have of sterilising a wound and rendering it fit for secondary suture, thereby making a wounded man fit to return to duty in the minimum time, and leaving him without the extensive painful scar which results from healing by second intention, an important point in the economy of the Army.

3. Without hesitation we can say that it has been the saving of many limbs in the series of cases treated at this hospital, because we have seen many limbs saved which would undoubtedly have been sacrificed, even as recently as the Somme offensive in 1916.

4. The dressings are painless, which is a great advantage, for constant dressings under an anæsthetic are extremely harmful to the patient because they lessen his morale and impede his progress.

5. The hourly or two-hourly instillation is appreciated by the patients. They say that it is refreshing and cool to the wound, and they remind the sister to the minute when it is due.

6. In this method we have definitely a standard way of treating all serious wounds. We have been fortunate enough to witness the evolution of the treatment of wounds from the beginning of this war, and have seen the undeniably ghastly results of the earlier methods of treatment. Since the advent of this system of treatment the whole outlook has changed, and to-day on this front and elsewhere we are witnessing the successful results of a universal and continuous treatment of wounds, which has surpassed anything previously tried.

7. It marks an important era in surgery, in that the objectionable method of wound drainage can be done away with, and though no doubt it will die a hard death, yet Carrel's method, we are confident, will supersede it.

8. Patients are able to get up and about sooner. The average stay in bed in this hospital per patient over 2,000 severely wounded cases has worked out at seventeen days!

What are the Disadvantages of the Carrel-Dakin Method?

1. **Increased Staff.**—This has not been so great as was at first anticipated. The secret lies in a thorough training of the nursing staff by lectures and demonstrations. We have found that sisters and V.A.D.s can carry out the treatment competently after a comparatively short period of routine training. They have grown enthusiastic at the results they have seen, at the painlessness of the dressings, the total absence of suffering in even the most gravely wounded, the absence of smell in the wards, consequently the remarkable absence of flies, even in an Eastern

climate, because there is no smell to attract them. A thorough acquisition of the technique diminishes the demand for an increased staff, and the use of Balkan supports has very greatly relieved the heavy work of lifting these patients. Further, the wounded men are soon able to get up and help themselves.

2. **Wetting of the Bed.**—This cannot always be avoided, but experience has made it a negligible factor. Still, there have been no cases of bedsore. If it is unavoidable, the use of an air pillow keeps the patient's back off the wet sheets.

3. **Complex Apparatus.**—In the Balkans we have not, perhaps, obtained the more refined apparatus procurable in the West, but douche-cans, rubber tubing, and glass nozzles, have given the desired results.

FIG. 96.—Enamelled douche-can used as a reservoir for antiseptic.

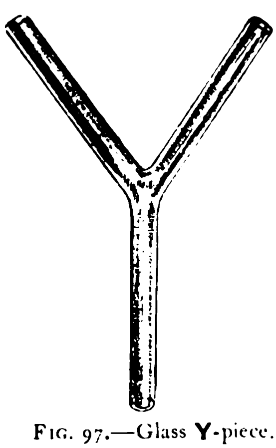


FIG. 97.—Glass **Y**-piece.

FIG. 98.—Glass nozzle for connecting the tube leading from the reservoir to the Carrel's tubes or the four-way glass-piece.

4. **Dermatitis from the Antiseptic.**—This complication has been entirely avoided by means of sterilised carbolised vaselin applied to the surrounding skin.

5. **Length of Time dressing a Wound.**—This is much shortened with

experience, and with practice the dressings can be completed in a shorter time than by the older methods.

Method of Instilling the Antiseptic into the Wound.—This can be performed—

(1) By gravity.
(2) By syringe.

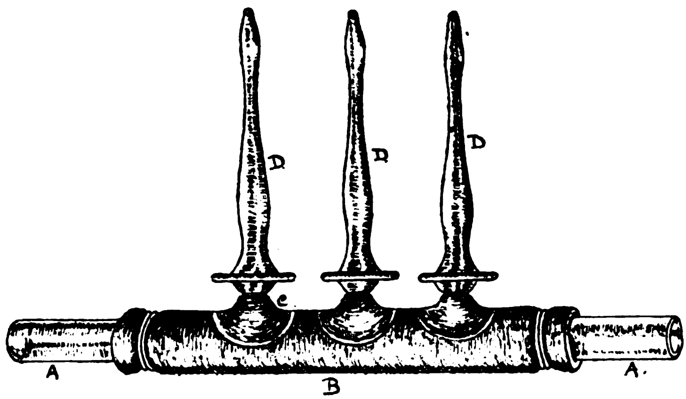


Fig. 99.—A three-way piece which can be attached to a douche-can reservoir, and can be made to supply three patients, as shown in Fig. 104.

A, two glass tubes fixed into a rubber tube, B; C, rubber nipples vulcanised to tube B; D, glass nozzles.

Fig. 100.

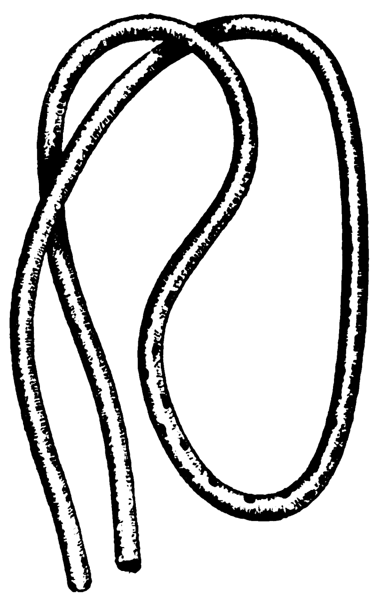


Fig. 101.

Carrel's tubes drawn to scale.

These tubes consist of rubber and are closed at one end. The tube is perforated at the closed end in a number of places, the perforations being made with a special punch. The longer of the two tubes is suitable for use in seton wounds or open amputation stumps.

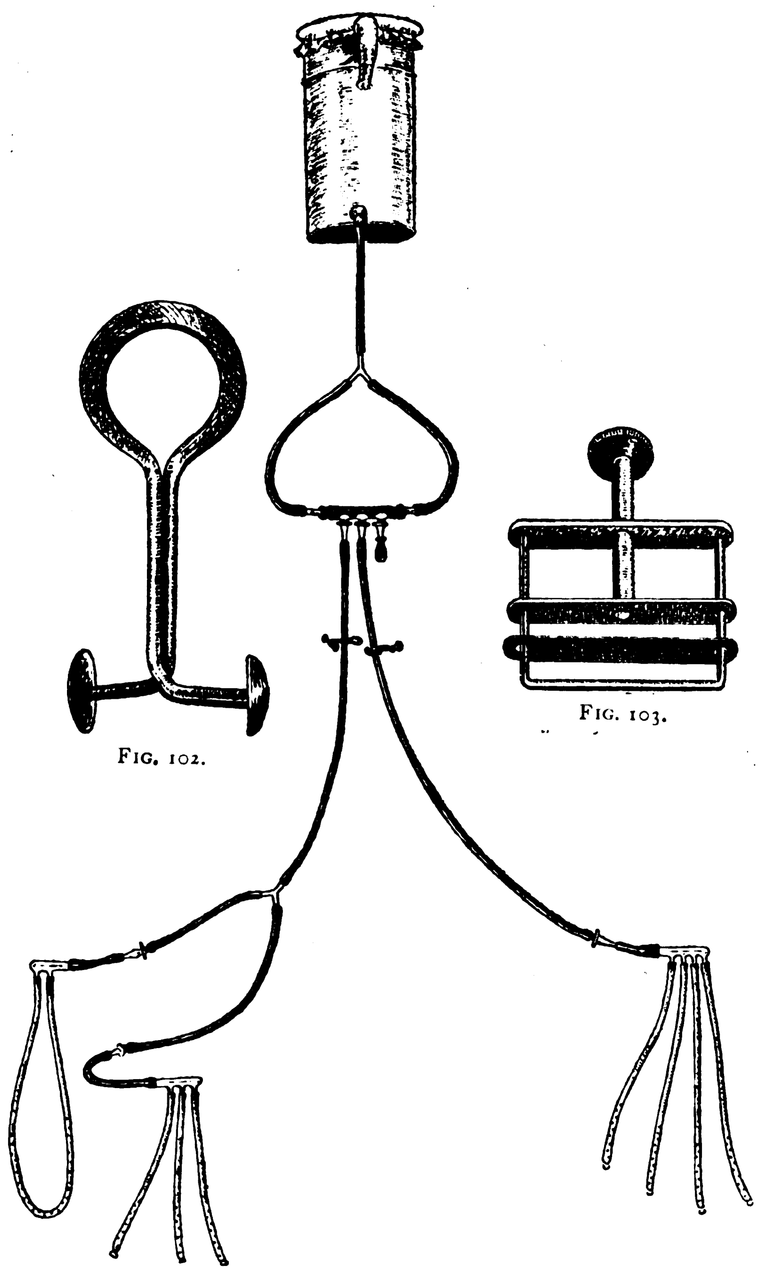


FIG. 102.

FIG. 103.

FIG. 104.

Apparatus suitable for the use of one, two, or three patients.

The first method can be carried out by means of a reservoir (an enamelled douche-can) placed about three feet above the level of the wound on the wall of the hut, or hung from the roof or side of a tent. To the douche-can is attached a rubber tube with a glass nozzle at the end, which can be introduced into the open end of the Carrel's tube or the tube which is fixed to the four-way glass piece. For practical purposes the clamp on the rubber tube leading from the reservoir is released, and the antiseptic is allowed to flow for three seconds into each Carrel tube. On the train or ship it is preferable to use a glass syringe unless a gravity apparatus is provided. If the height to which the reservoir is raised causes pain, then it should be lowered until the correct head or pressure is reached. An automatic apparatus for administering the antiseptic is shown in Plate IV.

The second method of instilling the antiseptic, by means of the syringe, is perhaps more accurate ; but if there are a number of tubes per patient and a large number of patients, it is a lengthy process and requires more staff. It is suitable, as stated before, for patients during transport by train or steamship.

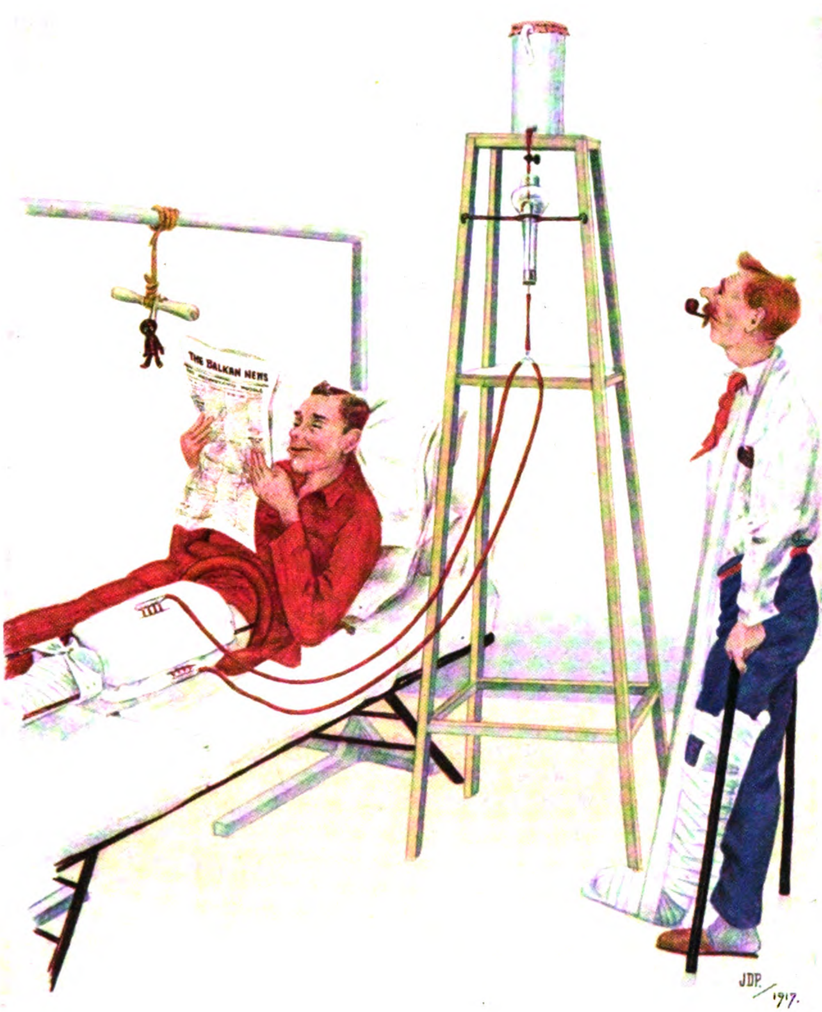
The most important part of the treatment of a wound rests with the surgical specialist at the casualty clearing station. It is he who must perform the necessary excision and apply the first Carrel-Dakin dressing, and on the thoroughness of this work depends the subsequent welfare of the case. We can here speak with authority, as we have worked for considerable periods both at a busy casualty clearing station and a base hospital.

During a rush it is impossible for a surgical specialist at a casualty clearing station to excise and deal with every wound, and of necessity he has to evacuate to the base hospital cases which in quieter times he would certainly retain. Of the rushes on this front we can give the valuable information that *in every case, however grave, in which the Carrel-Dakin treatment, very imperfect as it was in some cases, had been started at the casualty clearing station, not a limb or life was sacrificed; but in many cases which appeared at the casualty clearing station to be of minor importance, and were therefore evacuated without the Carrel-Dakin treatment, gas gangrene had supervened by the time the base hospital was reached, and both limbs and lives were lost.*

These salient facts so strongly impressed us that we are now of opinion that if the work at the casualty clearing stations is more than the surgeon there can deal with, then it is very advisable to apply a Carrel-Dakin dressing to the wound as it exists on arrival there, and send the case direct to the base hospital, rather than to trust to an ordinary dressing.

Wounds associated with Uncontrollable Hæmorrhage.—There is still a class of wound, well known to the surgical specialists, and usually associated with compound fracture of the upper end of the tibia, or the upper ends of the bones of the forearm, especially the ulna, or associated

PLATE IV.



An automatic apparatus for intermittent instillation of an antiseptic into wounds. An enamelled douche can act as a reservoir containing the antiseptic. The antiseptic is allowed to drip from the reservoir into an inverted lamp glass. Into the lamp glass is inserted a glass tube bent at the end in the form of a U. As soon as the fluid reaches the upper limit of the bend in the tube it is automatically discharged down the rubber tube into the wound. By regulating the rate of drip from the reservoir the fluid can be made to flow into the wound hourly or two-hourly. The amount of fluid syphoned off can also be regulated by attaching a piece of rubber tubing to the shorter limb of the glass tube. This apparatus has worked satisfactorily and has supplied three patients. A patient who is getting about on crutches is told off to see that each hour the apparatus works satisfactorily.

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with a penetrating wound of the interosseous membrane of the forearm about its middle, in which hæmorrhage of an uncontrollable nature occurs.

It is often impossible to find the divided ends of the vessel, and the more ligatures that are applied, the more persistent seems the hæmorrhage. It is this class of wound in which it is both justifiable and good practice to apply a salt pack. This must be put on after the wound has been cleaned and excised, a tourniquet being used the while. It is very important to pack tightly every pocket and diverticulum of the wound, and after the cotton-wool has been applied, to fix the dressing securely with a bandage. When the tourniquet has been removed, the limb should be well elevated on a pillow, and steadied with a convenient straight splint. The surgeon should not allow the case to leave the theatre until he has made a careful examination of the hand and foot, whichever it may be, and is thoroughly satisfied that the circulation is still present. It has happened that a salt pack well applied in a deep wound of any extent has by pressure been sufficient to arrest the circulation in the part of the limb below, and gangrene has resulted.

All fractures must be dealt with and thoroughly immobilised prior to transit to the base hospital. This subject will be referred to in a special chapter.

The work of the surgical specialist at a busy casualty clearing station is both arduous and difficult. Often he has to work day and night, and under these conditions he cannot keep up the same standard of work that he could had he fewer cases to deal with, as in the quieter periods. He has, in addition to the excision of large gangrenous wounds, numerous other cases, requiring abdominal section, craniectomy, and amputation, to deal with, all of which call for anxious attention in the after-treatment. A number of his cases die, and he begins to worry, and to think over small things he has left undone that might have been done. He must remember that a number of cases are bound to die, and if for a brief spell he can count up his successes and his failures, he will always find that the balance lies well on the side of success. War is war, and as long as a surgeon is conscientiously doing his best, there is no need to worry, for worry is a powerful deterrent to good work.

Treatment on the Hospital Train and Ship.—This consists in attending to the general needs and comfort of the patients, and in the hourly or two-hourly instillation of the antiseptic into the tubes. The latter is best carried out with a glass syringe. One argument against the Carrel-Dakin treatment was the want of continuity during transport. This has been shown to be a fallacy both in France and in the East. Every patient gets his hourly dose on the train, and from what we have learned from the train staff in the East, it can be carried out both easily and efficiently. Should a severe hæmorrhage occur on the train or ship, though this is fortunately rare, prompt surgical measures must be taken for its arrest, and these can usually be carried out without stopping the train.

Treatment at the Base Hospital.—Convoys arriving at a base hospital are dealt with as rapidly and efficiently as possible. At this particular base hospital segregation of cases has, whenever possible, been practised. Thus, all amputation cases have been put into one ward. All wounds of chests, wounds of the head and spine, compound fractures of the lower extremity, compound fractures of the upper extremity, wounds of joints, and abdominal injuries, have respectively been nursed in separate wards.

By these means certain sisters and medical officers get accustomed to, and familiar with, the treatment of a certain class of wound, and the scheme of segregation has proved itself the best both as regards efficiency and economy.

Changing the Ward Staff.—It is of the greatest importance not to change the staff of any particular ward unless it is absolutely necessary, as the sudden substitution of a new sister or a new medical officer often spells disaster. No new sister or medical officer, especially if untrained in the Carrel-Dakin system, can pretend to take the responsibilities of a ward full of serious cases ; consequently the patients suffer, time is lost, and efficiency impaired, to say nothing of the increased expense to the State.

In the East, owing to tropical sickness amongst officers and sisters, we have unfortunately had to put up with this inconvenience, and in this way we have been handicapped.

Treatment of the Wounded on Admission.—The severely wounded men are taken direct to the wards after their field cards have been collected at the admission and discharge room, and are put straight to bed, their kit being handed in to the pack store. In the wards they are divested of their clothing, supplied with a clean pyjama suit, washed, fed, and allowed to sleep. For most of these tired men no hypnotic is necessary, and in many cases they fall asleep for twelve hours or more. No man, unless it is absolutely necessary, is taken to the operating-theatre on arrival. Far more important to his welfare at this stage is a good rest and a sleep. For the foulest of wounds we have adopted this practice, and have seen only good result. It is the greatest mistake in the world to hurry a wounded man, unless there be severe hæmorrhage or an abdominal condition necessitating immediate interference, into the operating-theatre immediately upon his arrival at a base hospital.

On the following morning the wounds are inspected. The majority of the wounds on this front have been dealt with at the casualty clearing station, and arrive at the base with a Carrel dressing applied. Cases of compound fracture of bone requiring better extension, cases of head wounds in which the scalp has been left unsutured, and cases of joints, especially the knee-joint, usually require further surgical treatment. In addition, limbs which are gangrenous or for other reasons useless, are dealt with on the day after admission, when the wounded men are better able to stand the necessary operation. May we once more emphasise the importance of commencing the Carrel-Dakin treatment as early as possible

in every case requiring it? Even though it be impossible through pressure of work to excise every wound at the casualty clearing station, it will pay a hundredfold if the surgeon or medical officer can find time to insert the tubes into a wound not excised, so that the instillation of the antiseptic can be carried out until the base hospital is reached. This latter

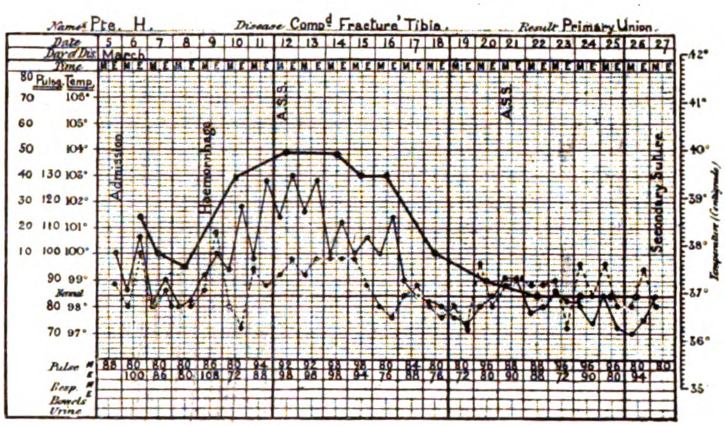

FIG. 105.

Thin line = temperature; dotted line = pulse; thick line = organisms per field.

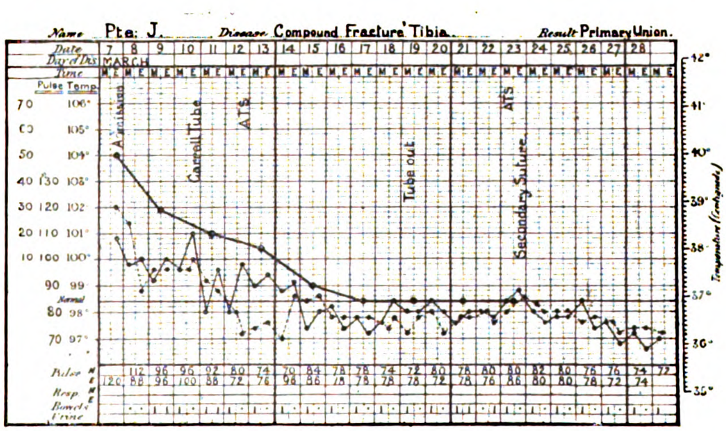

FIG. 106.

Thin line = temperature; dotted line = pulse; thick line = organisms per field.

procedure has proved its worth times out of number. All wounds treated by the Carrel-Dakin treatment at the casualty clearing station are similarly treated at the base hospital. Wounds not so treated, but which are suitable, are immediately submitted to Carrel's system. Wounds of large extent which are insufficiently patent are stitched widely open and the Carrel-Dakin dressing reapplied.

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Bacteriological Control of Wounds.—From each of the wounds smears are taken by the medical officer or sister in a manner described on

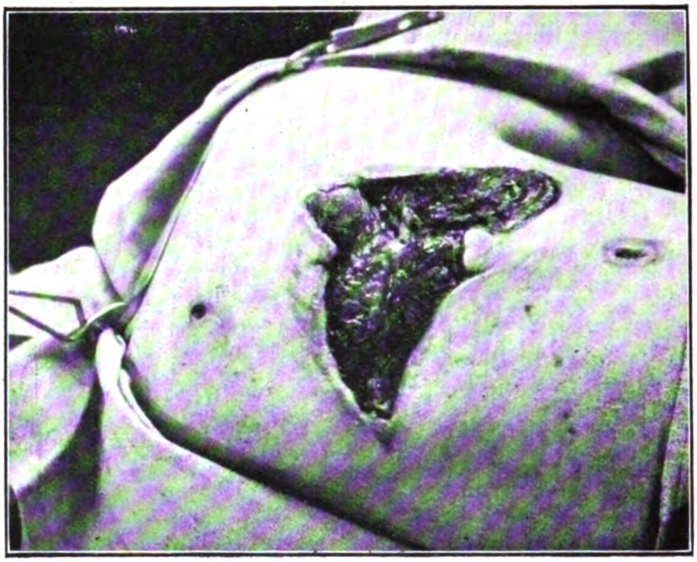


FIG. 107.—Wound of shoulder sterilised and ready for secondary suture.

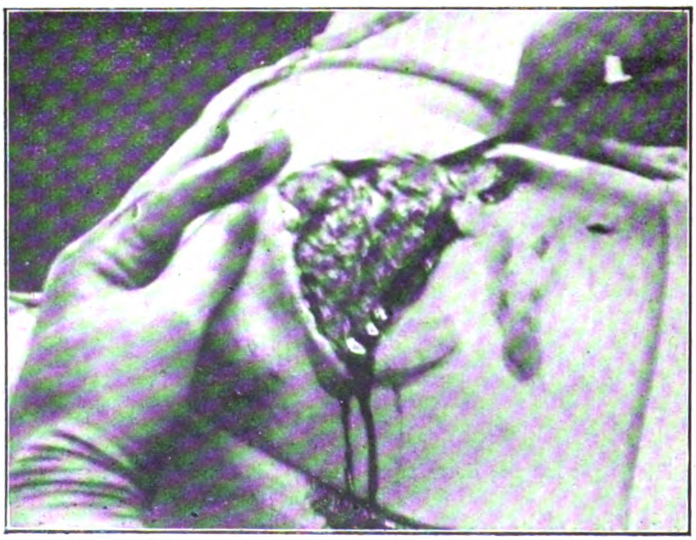


FIG. 108.—Wound of shoulder, showing first stage of secondary suture. The scalpel is made to incise the tissue at the junction of the skin edge and granulation tissue.

pp. 104 and 105, and sent to the bacteriologist for examination and report. The number of organisms per field taken over a number of fields forms

FIG. 109.—Same wound of shoulder : undercutting of skin edges.
(The photograph from which this illustration was reproduced was accidentally printed from the negative turned the wrong way round.)

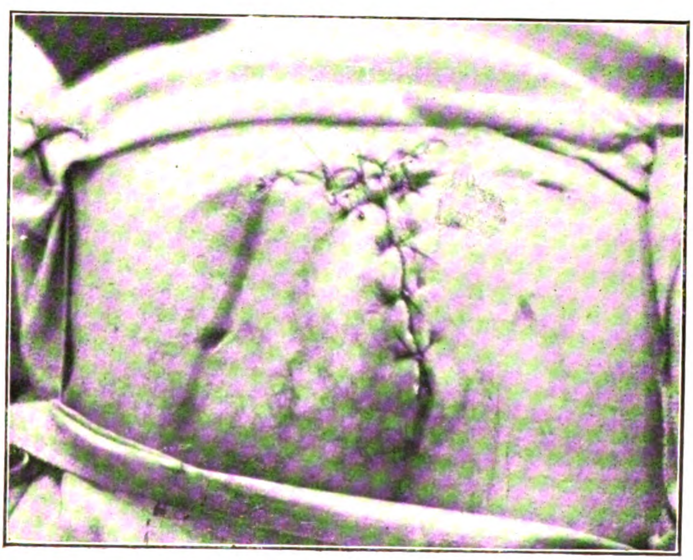


FIG. 110.—Same wound after suture.
Healing by primary union followed.

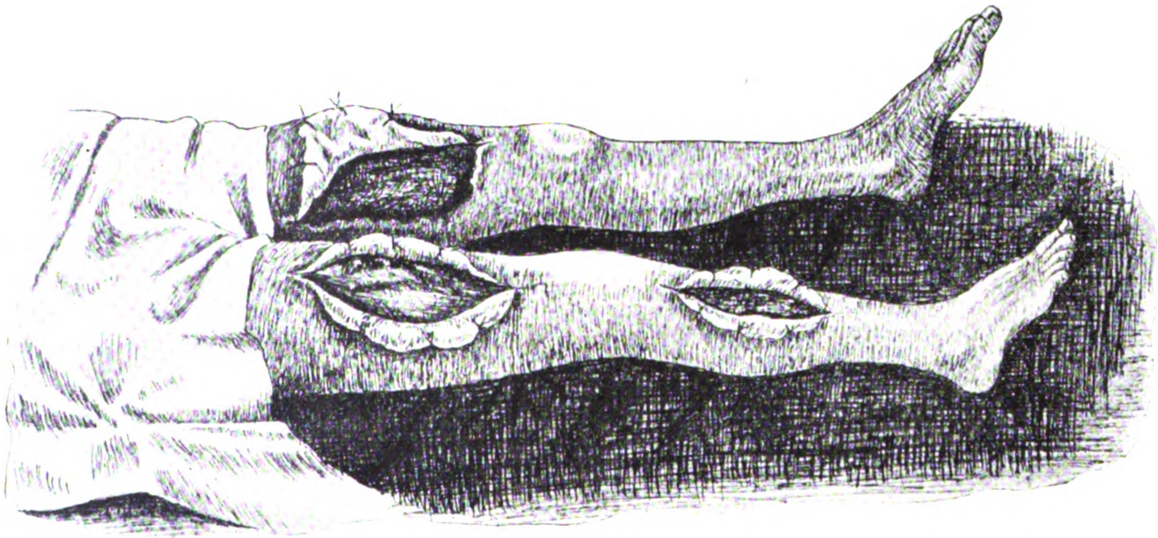
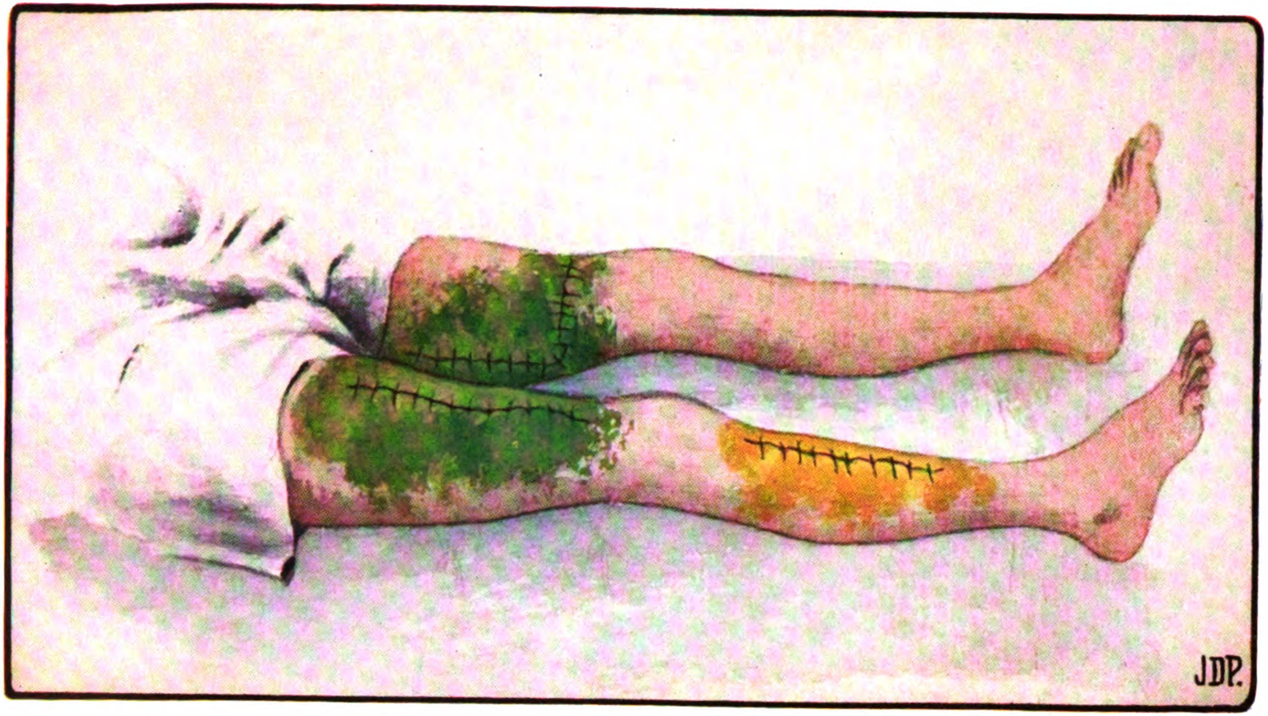


FIG. 111.—Drawing of a case of compound fracture of both femora and of the right tibia and fibula. Note the wounds are sewn widely open to permit of sterilisation.

PLATE V.



The same wounds sterile and sutured six days after infliction. Both thigh wounds healed *per primam* but the leg wound opened in one place to the extent of two inches. It subsequently healed and there was union in all bones at the end of five weeks.

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the surgeon's guide as to the progress of the wound. When this count shows not more than 0·2 organism per field, such smears being taken from every part of the wound, the wound is ready for secondary suture.

Secondary Suture.—After preparation, which involves an aperient and thorough cleaning and shaving of the skin, the patient is anæsthetised.

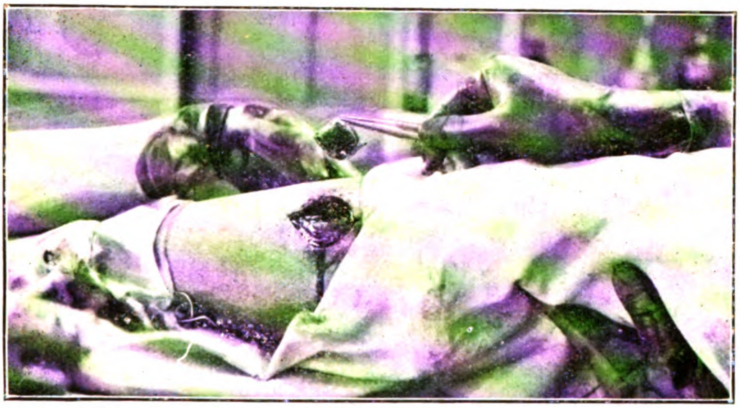


FIG. 112.—Compound fracture of tibia.
This wound, though highly infected, was sterile and ready for suture at the end of twelve days

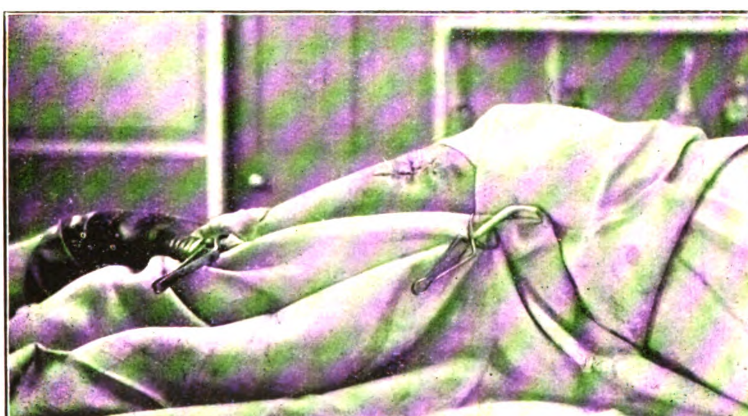


FIG. 113.—Same wound sutured.
The wound healed *per primam*.

It has been our practice to shave the pubes, anus, perineum, and scrotum the day after admission in all cases in which the buttocks, thighs, legs, back, or abdominal wall have been involved, in addition to shaving the whole limb, and also to shave the axilla and limb in cases of wounds of the upper extremity. The skin around the wound is washed with ether and painted

with iodine, and the wound itself is first sponged over with normal saline, followed by ether. The surface during the operation is swabbed with flavine, of strength 1 in 1,000 in normal saline, or with the hypochlorites.

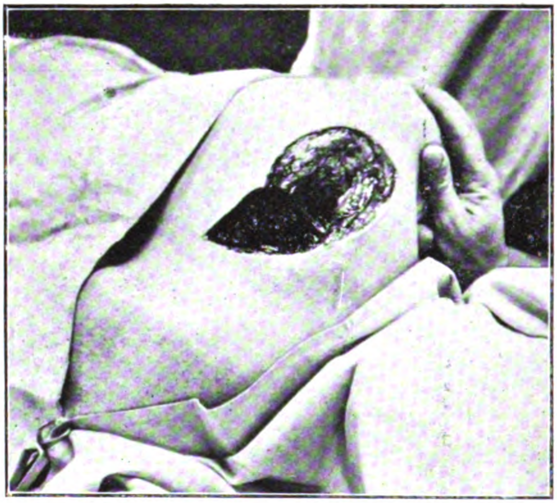


FIG. 114.—Large wound of back involving an extensive fracture of the scapula. The wound has been excised.

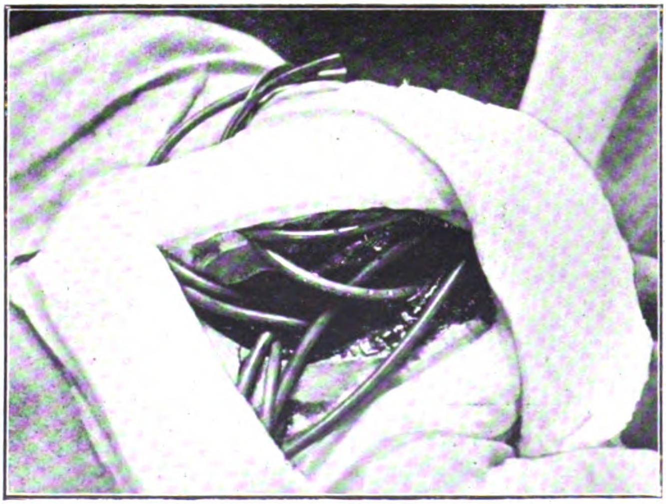


FIG. 115.—Same wound with Carrel's dressing applied.

A scalpel is now used to incise the periphery of the wound at the junction of the skin and the wound surface down to the deep fascia. This must be carried out in such a way that the opposing surfaces to be sutured

are perpendicular to the skin edge, and there will be, consequently, no turning in of the skin edge along the suture line. This done, the skin is

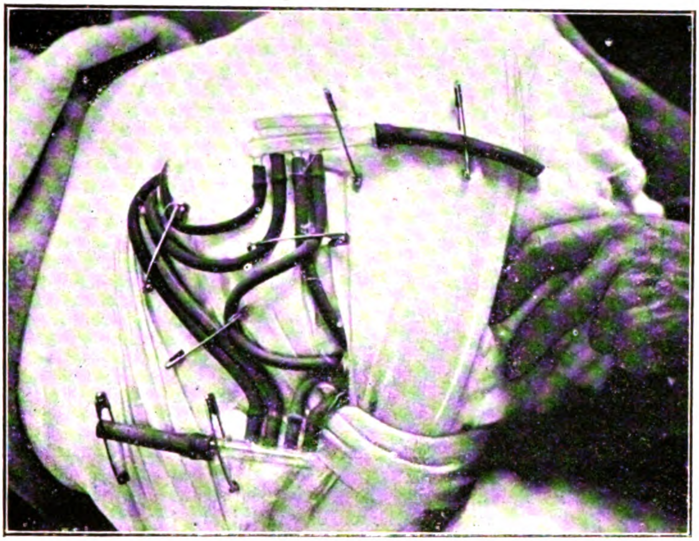


FIG. 116.—Same wound with dressing complete.

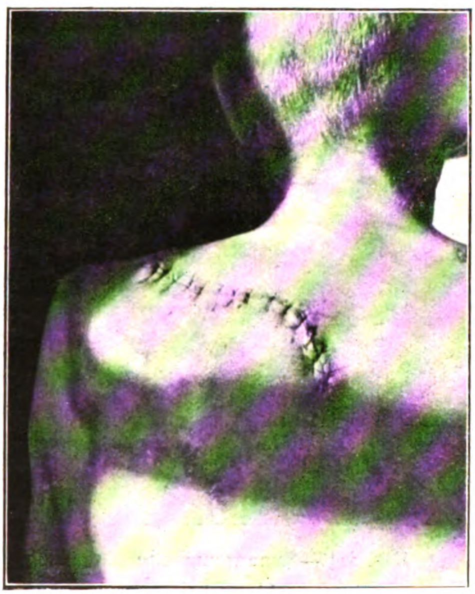


FIG. 117.—Same wound ten days later, sutured.
Wound healed *per primam*.

now undermined to a sufficient degree to allow the edges to be approximated with the smallest amount of tension. The suture is now effected

by means of tension and approximation stitches. The tension stitches, usually of double-strength silkworm-gut, and threaded preferably through a piece of small-calibre rubber tubing, are first inserted and tied.

FIG. 118.—Extensive wound involving the shoulder-joint and highly infected, ready for suture at the end of a fortnight.

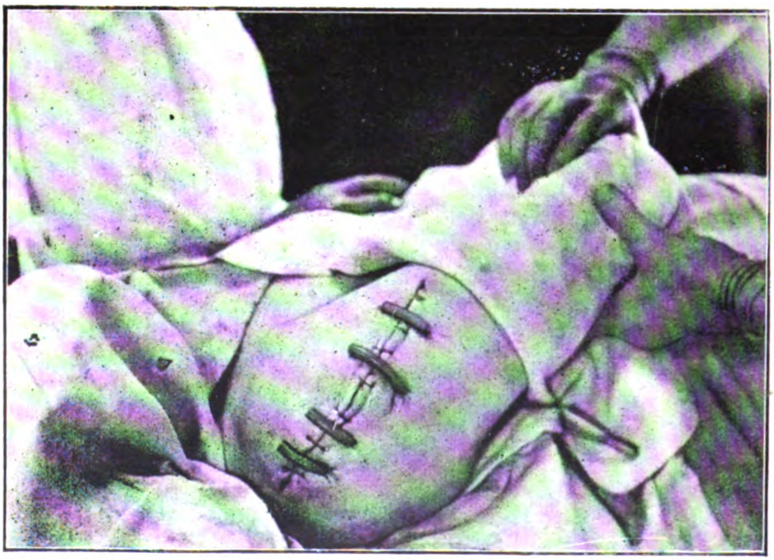


FIG. 119.—Same wound after suture.
The wound healed *per primam*.

The number of tension stitches required will vary with the size of the wound.

The approximation stitches of single-strength silkworm-gut are next

inserted in such a way as to slightly evert the skin edges. These are placed at intervals of half an inch along the whole suture line.

This done, the suture is complete, and wet dressings of hypochlorite,

FIG. 120.—Large wound of thigh, sterile and ready for suture.
This wound ten days previously was foul and contained gas infection.

FIG. 121.—Same wound sutured.
Healed *per primam.*

flavine, or brilliant green are applied. Wool and a bandage complete the dressing, and if the wound be that of a limb, the limb is put up on a splint.

The sutures are removed at the end of the tenth day. We have not used Michel's clips.

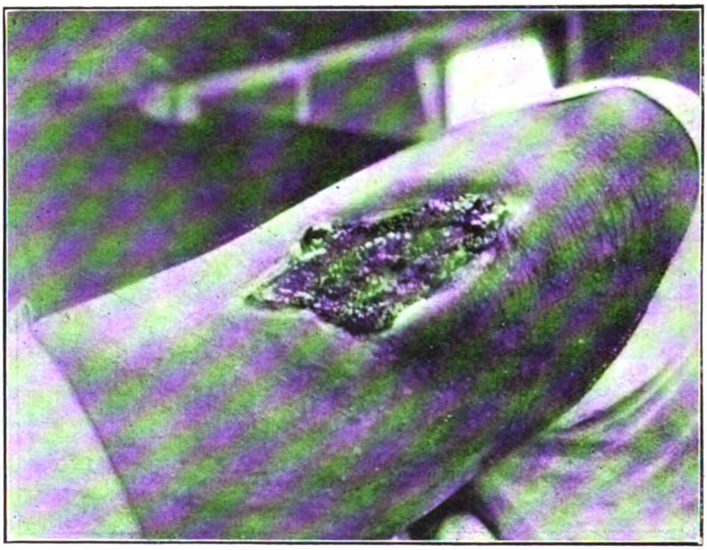


FIG. 122.—Compound fracture of tibia.
Wound, which was grossly infected, ready for secondary suture in fourteen days after infliction.

FIG. 123.—Same wound after suture.
The wound healed *per primam*.

In all cases of large surface and deeper wounds undergoing sterilisation there is a great tendency to retraction of the skin and tissues, which is certain to involve tension on the sutures when the time for closure of the

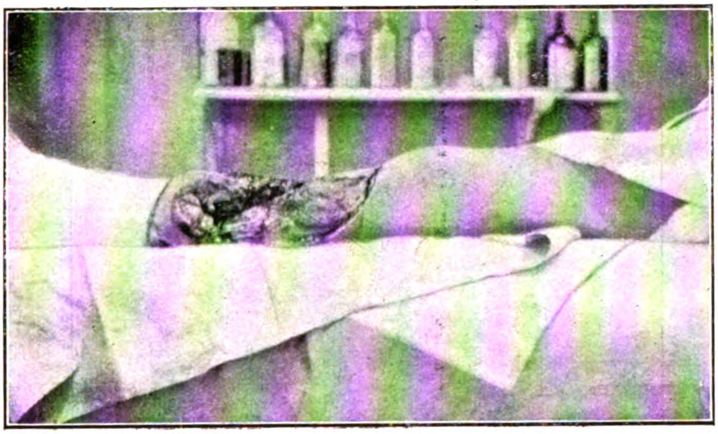


FIG. 124.—Severe wound of leg with compound fracture of the tibia; highly infected.

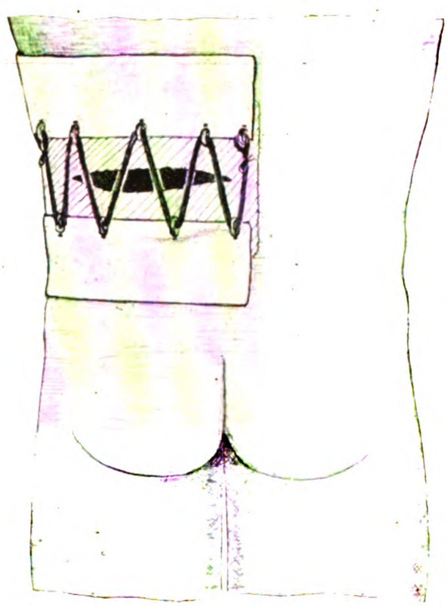


FIG. 125.—Corset applied and laced to a gaping wound in the back so as to prevent undue retraction of the wounded edge.

wound falls due. Their retraction can be overcome by means of the corset shown in Fig. 125. The gauze or other sterile fabric is fixed to the skin by adhesive such as Page's glue. A thin rubber lace, by its constant traction, draws the skin edges together and prevents retraction.

Length of Time for Sterilisation of a Wound.—The length of time that a wound requires for sterilisation depends almost entirely upon the time that has elapsed between its reception and the beginning of treatment. The shorter this interval, the shorter the time for sterilisation.

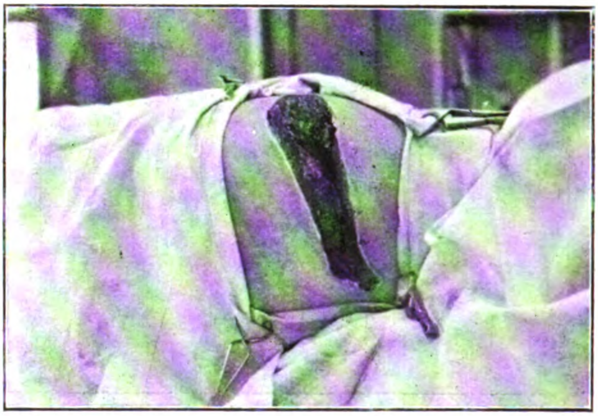


FIG. 126.—Large wound of buttock, which contained gas infection, sterile and ready for suture eight days after infliction.

FIG. 127.—Same wound after suture.
Wound healed *per primam.*

Sterilisation in wounds of the soft parts only has been as rapid as four days and as late as fourteen days. The average time is about eight days.

When bone is involved, the interval of time elapsing between receiving the wound and sterilisation has varied from six to twenty-eight days, depending upon the amount of the comminution, the time elapsing between the reception of the wound and the commencement of treatment, and the way in which the fracture has been immobilised.

FIG. 128.—Wounds of both buttocks sterile and ready for suture.

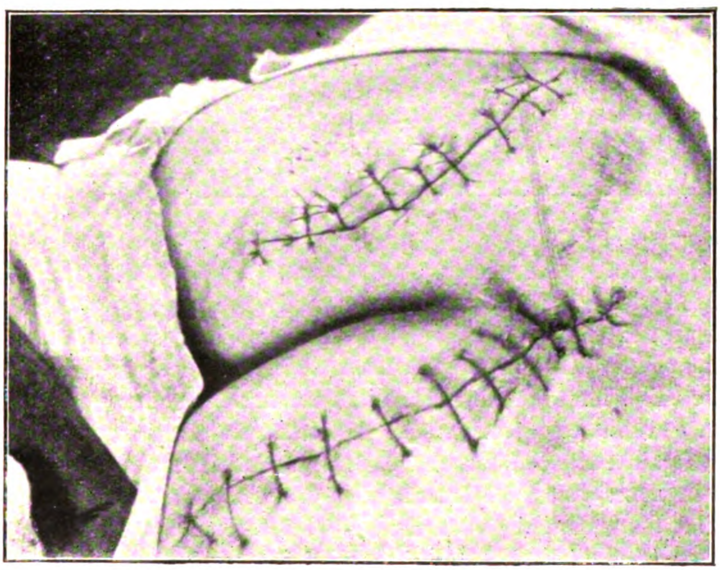


FIG. 129.—Same wounds after suture.
Wounds healed *per primam.*

Length of Time spent in Bed.—There is no doubt whatever that one of the greatest errors in the after-treatment of wounds is prolonged rest in bed. Wounded men waste rapidly ; they lie in bed and brood over their lot, and ultimately, if they are allowed to keep their beds long enough, they show a distinct disinclination to get up. Not only is their morale decreased by this practice, but the work of the nursing staff is made both heavy and difficult.

It has been our practice to get these men out of bed at the earliest possible moment, and nothing but good has resulted. Men suffering from fractured humerus, fractured forearm, fractures of the bones of the leg, tarsus or metatarsus, are got out of bed at the end of the fourth or fifth

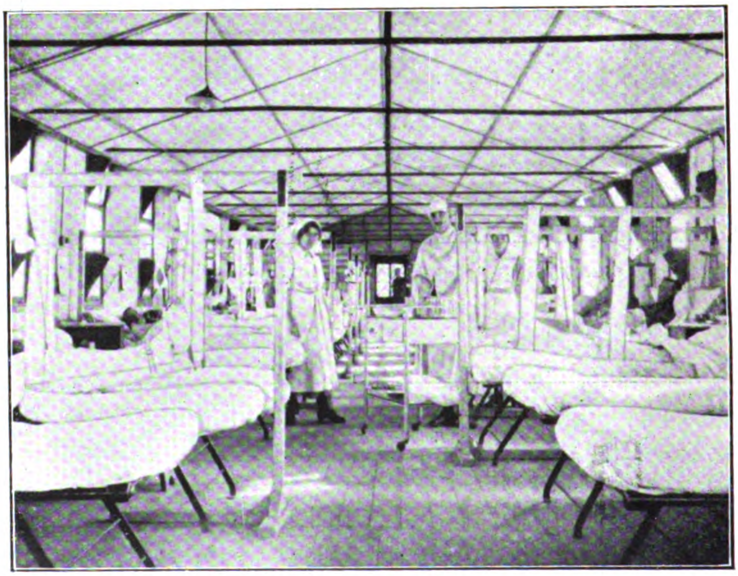


FIG. 130.—Ward set apart for knee-joint injuries and compound fracture of the femur.

day. Men with fractures of the humerus or forearm put up on a Thomas's straight arm extension splint are made to walk with a comrade who supports the splint, while men with fractures of the lower extremity other than the thigh immobilised with suitable splints get about on crutches, the damaged limb being slung from the neck. Not only do wounds sterilise much quicker by these means, but the wounded men at once get confidence in themselves ; they realise that their wounds are not so serious as they at first thought ; they eat better and sleep better, their whole outlook on life is altered, and the work of the nursing staff is lightened. Chest-wound cases have been got up into chairs at the end of the seventh day and carried out of doors. Out of 150 chest-wound cases no harm occurred, but good only resulted. Cases of compound fracture of the

femur, when once thoroughly immobilised on a Wallace-Maybury splint and undergoing continuous sterilisation, have got up in a chair at the end of a week. The change for the good in these latter cases is almost incredible, and we have very few cases of this latter condition in which these men were not up on crutches in a Thomas's trench splint with their wounds

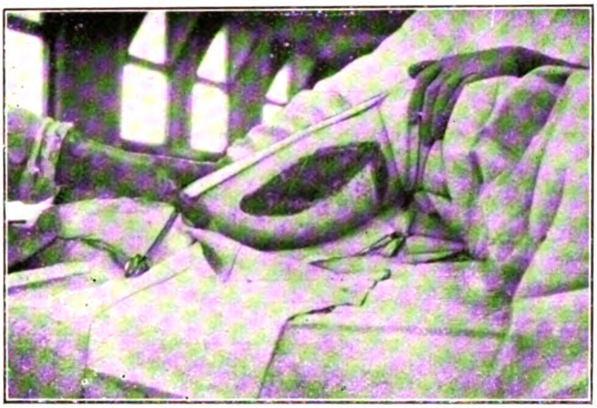


FIG. 131.—Large, highly infected gunshot wound of the leg, sterilised in eight days.

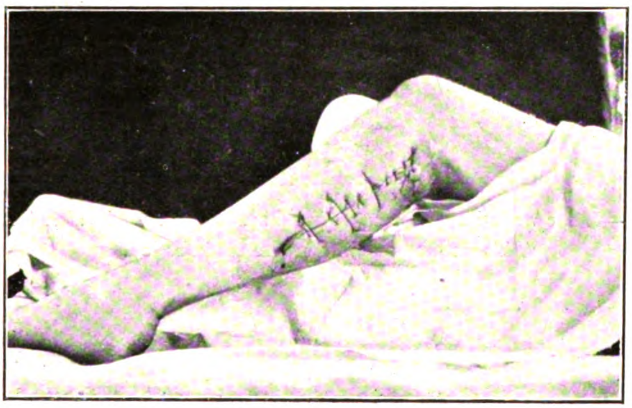


FIG. 132.—Same wound sutured.
Wound healed *per primam.*

sutured and healed at the end of six weeks from the date of their injury. There were several who were up on crutches at the end of the fifth week and a few at the end of the fourth.

Abdominal cases have been up and about at the end of three weeks, and most joint injuries at the end of the second week.

Head cases as a routine have been kept in bed for one month.

In not a single case out of a series of 2,000 consecutive seriously wounded

men have we seen any harm whatever result in getting them out of bed early, but in every case good has accrued.

This, indeed, is in great contrast to what one saw even a year ago.

Early getting about, in cases of wounds of the lower extremity, especially fractures, has brought about a far more rapid sterilisation. It is not going too far to suggest that such ambulatory treatment has a therapeutic significance, in that on the top of the continuous sterilisation by the Carrel-Dakin scheme there is superadded the element of passive congestion.

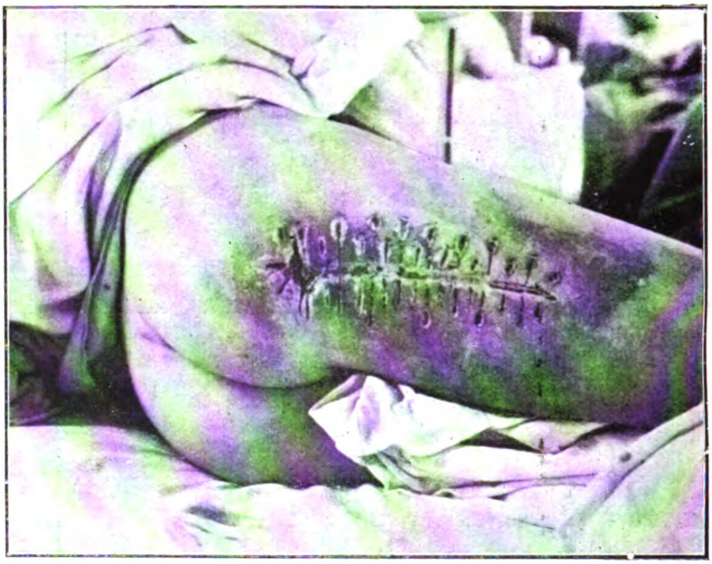


Fig. 133.—Large wound of thigh sutured and healed three weeks after infliction. This wound contained severe gas infection.

Continuity in Treatment.—On the Eastern front we have had the opportunity and good fortune to witness the result of a continuity in treatment of wounds between firing-line and base, and in this respect our experience here differs from that in the Western theatre. In the Western theatre, where the number of casualties were large—for there it was a matter of dealing with a larger army and constant fighting—the one important point was to get the wounded to the base as rapidly as possible. The base hospitals in turn had, of necessity, to resort to immediate evacuation of their wounded to England. From the hospitals in England the wounded were, before their wounds were healed, moved on to convalescent homes in different parts of the country. The wounded man, therefore, within a comparatively short space of time, had passed through many hands, and possibly received a different treatment at each institution.

In the Eastern theatre we had, of necessity, to keep the wounded until

their wounds were healed and they could look after themselves on a hospital ship in the event of its being torpedoed or struck by mines. No lying

FIG. 134.—Two cases of compound comminuted fracture of the femur up on crutches five weeks after infliction of the wound.

FIG. 135.—Four cases of compound comminuted fracture of the femur up on crutches five weeks after the infliction of the wound.

cases could, therefore, be taken on board, and no cases of amputation or fracture unless the stumps or wounds were soundly healed.

The Carrel-Dakin treatment in the Salonika army then became universal. Wounds were dressed early after infliction at the field ambulances with the hypochlorites, and in a number of cases Carrel's tubes were introduced. If this was not possible, the wounds were filled with hypochlorite solution and the wounded were moved on to the casualty clearing stations without delay.

At the casualty clearing stations the wounds were excised and a Carrel-Dakin dressing applied, after which the wounded man was sent on at once to the base hospital, if fit to travel. If not fit, he was detained at the casualty clearing station, where the treatment was continued. On the hospital train each man received an hourly dose of the antiseptic through the tubes during the journey to the base. On arrival at the base hospital he was put straight to bed, and instillation of the hypochlorite into his wound was carried on until the next day.

In a number of the cases arriving from the casualty clearing stations a bacterial count of organisms per field, taken at the last dressing, accompanied the notes.

The day after arrival at the base hospital the wounds were inspected, the tubes replaced, and a bacterial examination of the wounds was made. This treatment was continued until the wounds were sterile, when secondary suture was performed.

We would like once again to emphasise the important observation, taken now over 2,000 consecutive cases of severe wounds, *that in all cases, however gross and severe, especially compound comminuted fractures of the femur and the like, where Carrel's treatment had been commenced early at the casualty clearing station, limbs and lives were saved; but in all cases where rush of work prevented the Carrel-Dakin treatment from being carried out, such limbs were gangrenous by the time the base hospital was reached, and had to be sacrificed, and in a considerable number of cases lives were lost.*

We cannot overestimate the immense importance of a system of continuity in treatment ; for to-day, when we see extensive compound comminuted fractures of the femur, which would a year ago have been submitted to amputation, united and healed and the man up on crutches at the end of six weeks ; cases of severe compound comminuted fracture of the humerus with union and good function at the end of five weeks, etc., it gives much ground for reflection. By the regularly organised standard method of wound treatment where continuity can be kept up, we are not only saving life and limb, a very important point in the economy of any army, but we are also saving much subsequent expense to the State.

Complications of Wounds undergoing Treatment.—To-day complications are exceedingly rare. Spread of infection, secondary hæmorrhage, septicæmia, embolism, and pyæmia, and certain tropical diseases, chiefly malaria and dysentery, are the main complications to be anticipated. These are all dealt with in other chapters.

Directions for the Preparation of the Solution to be used with Carrel's Apparatus

The ORIGINAL DAKIN SOLUTION was prepared as follows:

140 grammes of dry sodium carbonate are dissolved in 10 litres of tap water, to which are added 200 grammes chloride of lime (chlorinated lime) and 40 grammes boric acid.

The DAKIN SOLUTION, TECHNIQUE OF DAUFRESNE, as now used, is prepared as follows:

Sodium hypochlorite solution for surgical use must be free of caustic alkali; it must contain only 0·45 to 0·50 per cent. of hypochlorite. Under 0·45 per cent. it is not sufficiently active and above 0·50 per cent. it is irritant.

With chloride of lime (bleaching powder) having 25 per cent. of active chlorine, the quantities of the necessary chemicals to prepare 10 litres of solution are the following:

Chloride of lime (bleaching powder) (25 per cent. Cl act.)	200 grammes
Sodium carbonate, *dry* (soda of Solway)	100 grammes
Sodium bicarbonate	80 grammes

Put into a 12-litre flask 200 grammes of chloride of lime and 5 litres of ordinary water, shake vigorously for a few minutes, and then leave in contact for six to twelve hours—say one night, for example. (Shake until dissolved—at least the big pieces—not all dissolves, large pieces float; notice only floating pieces.) At the same time dissolve in 5 litres of cold ordinary water the carbonate and bicarbonate of soda. After leaving from six to twelve hours, pour the soda solution into the flask containing the macerated chloride of lime, shake vigorously for a few minutes, and leave time to allow the calcium carbonate to be precipitated. In about half an hour, siphon the liquid and filter with a double paper to obtain a good clear liquid, which should always be kept in a dark place.

TITRATION OF CHLORIDE OF LIME (BLEACHING POWDER).

Owing to the variation of the products now on the market, it is necessary to determine the quantity of active chlorine contained in the chloride of lime which is used. This is in order to employ an exactly calculated quantity according to its concentration.

The test is made in the following manner:

Take from different parts of the jar a small quantity of bleaching powder, to have an average sample, weigh 20 grammes of it, mix as well as possible in a litre of tap water and leave in contact for a few hours. Measure 10 c.c. of the clear liquid, and add 20 c.c. of a 10 per cent. solution of potassium iodide, 2 c.c. of acetic acid, to free all hydrochloric acid, then put drop by drop into the mixture a decinormal solution of sodium hyposulphite (2·48 per cent.) until decoloration. The number of cubic centimetres of hyposulphite solution employed, multiplied by 1·775, will give the weight in grammes of active chlorine contained in 100 grammes of chloride of lime.

The test must be made every time a new product is received. The result obtained will differ more or less from 25 per cent. and it will be necessary to reduce or enlarge the proportion of the three products contained in the preparation This can easily be arranged by multiplying each of the three numbers: 200, 100, 80, by the factor $\frac{25}{N}$, in which N represents the weight of the active chlorine per cent. of chloride of lime.

TITRATION OF DAKIN-DAUFRESNE SOLUTION.

Measure 10 c.c. of the solution, add 20 c.c. of a 10 per cent. solution of potassium iodide, 2 c.c. of acetic acid, and drop by drop a decinormal solution of sodium hyposulphite until decoloration. The number of cubic centimetres used, multiplied by 0·03725, will give the weight of hypochloride of soda contained in 100 c.c. of the solution.

Never heat the solution, and if, in case of urgency, one is obliged to resort to trituration of chloride of lime in a mortar, employ only water, never salt solution.

TO TEST THE ALKALINITY OF THE DAKIN-DAUFRESNE SOLUTION.

To differentiate the solution obtained by this process from the commercial hypochlorites, pour into a glass about 20 c.c. of the solution and drop on the surface of the liquid a few centigrammes of phenolphthaleïn *in powder*.

The correct solution does not give any coloration, while Labarraque's solution and eau de Javal will give an intense red colour, which shows the presence of free caustic alkali.

The stock solution should be kept in blue or brown coloured bottles, well corked.

It will be readily seen that there is a difference between the Dakin's solution as originally made and the hypochlorite solution, technique of Daufresne. The original solution contained 0·5 to 0·6 per cent. sodium hypochlorite, the modified Dakin solution contains between 0·45 to 0·50 per cent. hypochlorite, and does not contain boric acid.

The method of use, technique Carrel, must be followed if successful results are to be secured. It is possible that the solution represents but 20 per cent., and that the technique of Carrel represents 80 per cent. of the result, but the success of the treatment is dependent upon the thoroughness with which it is applied and the care given to even the smallest details of the technique.

CHAPTER XVI

NURSING ON ACTIVE SERVICE

BY

Miss C. T. Bilton, Q.A.I.M.N.S.

Probably never before in history has the nursing profession had so thorough an awakening as it has experienced, and is still experiencing, in this great war.

Nurses have had to move quickly, by themselves, from place to place, under circumstances both difficult and inconvenient, and amongst people of unknown ways and languages. They have had to put up with worries and anxieties never imagined or dreamt of before ; but this has been the golden opportunity for a woman to show what she is worth both as regards common sense and resource. Many of the profession have experienced both enemy shell fire and aerial raids. A number have joined the great majority, the result of wounds or disease, leaving behind them a memory and an example which will be cherished by those who are left to carry on.

Duties of the Nursing Staff.—As a whole, nurses are difficult to move out of a regular routine ; one might almost call it a rut. They have gone through a course of training in civil life, where everything runs smoothly and all the requisite necessities are immediately forthcoming.

Most nurses who have joined the Army do not reckon with the fact that highly important duties other than nursing and the care of their patients come within their province, and that these require careful thought, coupled with no small knowledge of organisation and administration.

Initiative and good management are the greatest necessities of the Army sister. New ways, new ideas, new treatment, differing from what she may have seen or have been taught at her training school, meet her each day. New methods, revealed and practised as a result of early failures in the treatment of wounds and disease, have sprung into existence, and are still being improved upon. The nursing staff must, then, give obedience and ready attention to carry out orders, which may seem at first sight meaningless, but which will always appeal to them in due course.

Unless a nurse is sufficiently intelligent and interested to grasp the fact that she is, of necessity, for the good of the Army, learning new and quicker

methods for restoring wounded and sick men to health and strength, and so enabling them to carry on in as short a time as possible, then she is a drag on the wheel of her unit, and the work must inevitably suffer.

My chief work has been in the Balkans, where the staff worked under great difficulties in a bad climate for ten hours a day over many weeks. The way they tackled the work was extraordinary, and no praise can be too great for them.

Want of water, the difficulties of heating (everything having to be boiled on a Primus stove), the despair of a nurse on active service, and the difficulties of working by the light of a hurricane lantern only, is beyond all description, and can only be imagined by those who have done it.

Discipline and management are the most essential assets in a charge sister. Discipline is easily kept, as the sister is dealing with men who understand what an order means, but she must always maintain this discipline.

The sister, although entirely responsible for the nursing, has also to requisition for the diets, to arrange and apportion the work of the ward to her nurses and orderlies, and to see to the cleanliness of her ward, and to the care, upkeep, and replacement of the ward equipment. She should always remember and impress on her nurses and orderlies the importance of ward cleanliness and hygiene, for neglect of these, specially in the East, favours the presence of flies, which are a potent source of disease and a dangerous menace to wounds. The methodical arrangement of her own work, as well as that of her staff, is the solution to coping with the enormous amount of work that there is to be done.

Work of the Ward Staff.—On active service a far greater number of patients come under the care of a sister than obtains in any civil hospital. In the particular hospital of which I had charge a sister on the medical side was responsible for ninety patients, her assistants being a staff nurse or a V.A.D., and three orderlies. On the surgical side one sister had charge of sixty beds, and she was helped by a staff nurse, one or sometimes two V.A.D.s, and two orderlies.

All patients, when convalescent, were transferred to convalescent wards. The orderlies' time was practically wholly absorbed in cleaning the ward, carrying the meals, drawing kits or handing them into store, as well as convoy duties, thus leaving practically all the nursing to be done by the female staff. Orderlies were provided at the rate of one to a thirty-bedded hut. This staff may sound inadequate, but the work was done, and the patients were well looked after and cared for.

Economy.—Economy we practised in every way, since the difficulty and uncertainty of transport added tremendously to the anxiety of keeping up the demand for stores. Everything that was possible to be used again was put to a second or third use. Ends of bandages, odd ends of wool from the disused padding of splints, if not stained, were collected in bags, and after sterilisation were made up into absorbent gamgee-like tissue.

This tissue, after being again sterilised, was used as an outer dressing instead of fresh wool.

Sawdust was tried in bags, but was not very satisfactory, as the dust, being coarse and from miscellaneous specimens of wood, was both heavy and difficult of management.

Nursing of Wounds.—The nursing of wounds has certainly been made easier by the method advocated by Carrel and Dakin, because the suffering by this method has been reduced to a minimum and the dressings are painless. This not only benefits the patient, but minimises the nervous strain on a nursing staff which has constantly to witness suffering.

The Carrel-Dakin treatment of wounds also decreases the work of the nursing staff considerably. The hourly or two-hourly instillation of the antiseptic into the wound is easily taught, and can be readily acquired by an inexperienced person, and if it is the duty of this person to see that it is regularly carried out, this will relieve the trained staff.

The hourly or two-hourly watering of the wound refreshes the patient, and the time for his "next drink," as he generally terms it, is eagerly watched for. The patient is not disturbed at night by the treatment, but continues to sleep through it all. The greatest difficulty, especially in wounds of the buttock or thigh, is to prevent the bed from becoming too wet. The proper padding of the wound at the dressing, and care that the correct amount of antiseptic only is instilled, with the precaution that the free ends of the tubes are not allowed to occupy a dependent position and so act as a siphon, will, for the most part, obviate this difficulty.

We found that a rubber ring-pillow to a great extent prevented the patient from lying on the wet bed. Draw-sheets we abolished, as even with a mackintosh this always meant an additional wet sheet to change. It was quicker and less disturbing to the patient when the foot-sheet only required changing.

Cleanliness is essential, not only to prevent bedsores, but to abolish all potential sources of infection. All that can be done towards preserving bodily cleanliness must be ever kept in mind. Dirty feet and uncut toe-nails, dirty hands with uncut finger-nails, long, unkempt hair with its concomitant scurf, unshaven chins, a soiled condition of the anus and perineum, specially if such be allowed to exist in a surgical ward, not only denote carelessness and neglect, but also act as a very grave reflection on the school at which the sister in charge was trained. Not only is it the sister's duty to have at heart and to see to the cleanliness and hygiene of the ward, but the cleanliness and personal hygiene of her patients are of equal importance ; and if these latter be neglected, it spells disaster to the aseptic progress of wounds. This is a point of extreme importance, and cannot be too strongly emphasised. An untidy ward, with an untidy and neglected condition of the patients, indicate an untidy sister.

Amputation stumps and badly wounded limbs from which hæmor-

rhage is likely to occur ought never to be covered with the bedclothes. Not only is it alarming to the patient to be constantly looked at, but it is easier to watch the dressing for any sign of hæmorrhage without disturbing him.

Morale of the Patients and the Ward.—Cheerfulness is an essential part of nursing. The patient must be encouraged to think that his one aim is to get well quickly and be fit again. The morale of a ward can be kept up by a sister who by her demeanour and work can show that it is her one aim to get her patients fit again. It may mean a lot of extra work to get a wounded man out of bed, if only for half an hour, but it must be remembered that this one act does an infinite amount of good in improving the patient's morale, for he immediately begins to think that his injury is not as serious as he thought it was. In consequence of getting these men out of bed, they sleep better, eat better, and their spirits and general condition rapidly improve.

In this hospital it has been the rule to get wounded men up *at the earliest possible moment.* In one ward where some of the heaviest cases were nursed, such as compound fractures of the femur, gunshot wounds of the knee-joint, compound fractures of the leg and upper arm, the average time in bed worked out at thirteen days. No disaster occurred from getting these men up early, but, on the contrary, the greatest benefit seemed to result, in that it had a marked effect for good on the patient's morale, and his general condition, besides allowing of proper and thorough attention to his bed.

The average time spent in bed for 2,000 consecutive patients, over 80 per cent. of whom were suffering from severe wounds, worked out in this hospital at seventeen days. This is a great saving of time, labour, and expense, both to the unit and the State, besides exerting a marked effect for good on the morale of the wounded man.

The feeding of wounded men is comparatively simple, for nearly all, except those wounded about the jaws or the abdomen, prefer and can take ordinary diet, and are far better for it. A prolonged course of slops or chicken and fish diet for wounded men, unless absolutely essential, is to be strongly condemned.

Treatment on Admission.—On admission, the first essentials are to make the patient comfortable, to feed him, to wash him, and then to let him rest. Most wounded and sick men arrive in a very tired and worn-out condition at the base hospital, especially if their stay at the casualty clearing station has been short. They have come straight from the battlefield, often a long distance, and with the shock resulting from their wounds, rest is most essential. They have usually been treated at the field ambulance or casualty clearing station, so that it is a mistake, unless absolutely necessary, to dress their wounds at once. Rest and sleep are far more essential at this stage.

Tented Hospitals and Huts.—Surgical cases are far harder to nurse

in a tented hospital. It is very convenient and often beneficial to be able to open the tent and practically nurse in the open ; but when the weather is bad the tent has to be closed, which renders it airless, dark, and dismal.

The huts, as usually built, are not altogether as satisfactory as might be. Those I had charge of were built for twenty-four beds, but of necessity the number of beds had to be increased to thirty. This allowed only just sufficient room for a locker between two beds. The width of the huts was insufficient, for when many Balkan supports or extensions were in use—and this was usually the case—the centre of the ward was very narrow.

Sweeping the ward under these conditions is difficult, as it is impossible to move the beds.

The arrangements for sanitation, especially in hot climates, are most important, as the drainage is not of the modern system one knows at home, but field appliances. What would seem to be the most suitable arrangement is that one end of the hut should be portioned off as a room for utensils, etc., into which the bed-pans can be emptied. This must be well ventilated, with a door leading to the outside, by which the sanitary brigade can enter when they come to empty the excreta and refuse. In this room there should be a covered tin into which the excreta can be emptied from the bed-pans, a bath of disinfectant for washing the pans, and a bath in which soiled linen can be steeped.

This apartment should be at the opposite end of the hut to that occupied by the scullery, and from which the food is issued to the patients. All patients able to get up should go to the latrines and washing-houses built outside for their use.

Nursing in the Balkans has been harder than many imagined. There was much sickness, which made matters just as severe on the nursing staff as on the troops. When a nurse went down with sickness this always entailed extra work on the others. Yet through it all we enjoyed the work, and the great majority of the nurses will always look upon their work in Macedonia as *the* event in their nursing career.

CHAPTER XVII

GUNSHOT INJURIES OF JOINTS

General Anatomical Considerations.

JOINTS are conveniently divided into—

(A) Mobile or diarthrodial joints.
(B) Immobile or synarthrodial joints.

Class A, which forms by far the greater percentage of all body joints, may again be subdivided into—

(1) Glabrous or gliding joints—*e.g.*, the temporo-mandibular and vertebral articulations.
(2) Ginglymus or hinge joints—*e.g.*, the ankle and wrist.
(3) Ball-and-socket joints—*e.g.*, the shoulder and hip.
(4) Rotary joints—*e.g.*, the superior and inferior radio-ulnar articulations.

Class B includes all suture joints, such as are seen in the skull, the joints formed between the epiphysis and diaphysis of long bones (synchondrosis or synostosis), the symphysis pubis, and the like.

Any injury sustained by a synarthrodial joint is but part of a more severe lesion of the bone or bones which form it; hence these injuries will be dealt with in the chapter dealing with gunshot injuries of bone.

Diarthrodial Joints.—The general plan of all diarthrodial joints is the same. They are formed by the cartilage-covered articular ends of bone; each is supplied with a synovial membrane, and some possess certain accessories in the form of intra-articular ligaments and cartilages (*cf.* the knee and hip joints), while surrounding all there is a fibrous capsule. Muscles and tendons operating upon a joint take their origin or gain their insertion into the bones in the immediate vicinity, and often, by sending tendinous slips to the capsule of the articulation, they enhance its strength. Around the larger joints is a rich arterial anastomosis, and in close relation are the main vessels and nerves of the limb. The articular ends of the bones are for the most part epiphysial, though this is not always the case.

The synovial membrane lines the inner surface of the joint capsule, and is reflected from this structure on to the intracapsular portion

of the bone as far as the articular cartilage, where it terminates in the synovial fringes.

In a unilocular joint the reflection of the synovial membrane is simple and uncomplicated, but in a multilocular joint (*e.g.*, the knee-joint) the reflection is both complicated and difficult. The synovial membrane is richly supplied with blood, the vessels running and ramifying in the subsynovial connective tissue. Thus it will be seen that these vessels lie between a yielding space (the joint cavity) on the one hand and an unyielding structure (the fibrous capsule) on the other.

The capsule of a joint is not of uniform strength throughout, but is reinforced in certain directions by thickened fibrous bands which constitute the ligaments.

Such, in brief, are the main anatomical features of a diarthrodial joint.

Physiology of the Synovial Membrane with regard to Infection.— Normally the synovial membrane secretes an oily fluid, which not only lubricates the joint, but is responsible for the vitality of the articular and intra-articular cartilages. The amount of synovial fluid secreted is just sufficient for the above needs, and normally its presence in the joint is neither visible nor palpable. Should the joint be subjected to injury, the synovial fluid is secreted in excess, and its presence at once becomes noticeable. The joint assumes a position in which its capacity for holding fluid is at a maximum, and remains thus until the excess fluid is partially absorbed.

The intra-articular tension in the synovial fluid of an injured joint varies, but it may be so great as to seriously interfere with the circulation in the vessels which run and ramify in the subsynovial connective tissue. If this is the case, the synovial fluid already secreted will become of low vitality, and therefore prone to infection.

Normally the synovial membrane, like the peritoneum, possesses a high power of resistance against infection, but if its vitality is interfered with—and this must inevitably occur when the joint cavity is distended with fluid under pressure—then infection of the joint contents is almost bound to follow if the joint has been penetrated or perforated by a missile.

Should infection of the synovial fluid follow, then death of the articular and intra-articular cartilages will result, as upon this fluid they are dependent for their maintenance,

If, on the other hand, there is an escape for the synovial fluid, and thereby a relief of the intra-articular tension, the circulation in the subsynovial vessels will be maintained and its vitality thereby enhanced. Foci of infection in a joint under the latter conditions tend to become shut off by adhesions, in the same way that an appendix abscess is shut off from the general peritoneal cavity. This we have seen happen time after time in damaged joints when the intra-articular tension has been early relieved, either by aspiration or through the joint being laid open by the missile

in such a way as to permit of the escape of synovial fluid. To sum up: "*The synovial membrane of a joint resembles the peritoneum in its powers to resist infection, and to shut off or localise foci of infection by the formation of protective adhesions, provided the intra-articular tension be early relieved and the joint put absolutely at rest.*"

Wounds of Joints.

These may be—

(1) Penetrating.
(2) Perforating.
(3) Indirect.

Penetrating wounds may be caused by rifle or machine-gun bullets, shrapnel balls, or pieces of high explosive. The missile may damage the soft structures only, or it may lodge in and fracture a bone. The extent of bony involvement may vary from chipping or guttering to most extensive comminution. On the other hand, the missile may penetrate the bone and come to rest in its substance.

Perforating wounds are the result of machine-gun or rifle bullets, or small pieces of high explosive, and they may or may not involve bone. Perforating wounds of the soft parts only, the result of rifle bullets, are often sterile, though a number have given rise to infection. On the other hand, perforating wounds, the result of high explosive, are practically always infected. Damage to bone may range from a clean perforation to most extensive comminution.

Indirect wounds are brought about by a missile striking and fracturing a bone at some distance from the joint cavity, causing a fissure in the bone which communicates with the joint, and bringing about a hæmarthrosis. The original wound is usually infected, and infection slowly travels along the fissure towards the joint at a fairly average rate of 1 to 2 centimetres per twenty-four hours.

Wounds in the neighbourhood of joints which neither involve the joint cavity nor bone will often give rise to a synovitis with effusion. The effusion is either pure or slightly blood-stained, and is rapidly absorbed. This not infrequent occurrence has been called by Makins a "fibrillary arthritis."

Dislocation of Joints is by no means uncommon, and results either from being buried or tossed by a shell. Dislocations caused by these means differ from those seen in civilian practice in that there is present considerable contusion of the soft structures, and very commonly fracture of bone.

Avulsion of Limbs through Joints.—These ghastly wounds appear to be caused by the rending force of high explosive, and were seen as the result of the bursting of Minenwürfers. For instance, a Minenwürfer exploded on a signaller's dug-out at ——. Nothing was seen of either of the two occupants of the dug-out beyond a leg in the German barbed wire some

two hundred yards away. The limb was recovered after dark by a patrol, and was found to be cleanly disarticulated at the hip-joint. On another occasion one of these missiles burst in the middle of a platoon proceeding along a communication trench at ——. Some of the victims showed avulsion of the upper extremity through the shoulder-joint, whilst others showed avulsion through the hip-joint. It is noteworthy that the two joints at which avulsion was most common were the hip and shoulder—that is to say, the ball-and-socket joints.

Infection of Joints.—Practically all penetrating and perforating wounds of joints, with the exception of some caused by rifle and machine-gun bullets, are infected. The course of the infection will depend upon several factors, which are in the main as follows :

(1) The general condition of the wounded man prior to receiving his wound—*i.e.*, the presence or not of fatigue or other debilitating causes.
(2) The presence or absence of other wounds complicating.
(3) The length of time that elapses between receiving the wound and the beginning of treatment. Many men hit in the knee-joint have been known to crawl to places of safety and lie for hours with a distended and mobile joint before being rescued.
(4) The retention of the foreign body, with its concomitant piece of clothing, in the joint cavity.
(5) Severe damage to the soft structures surrounding the joint.
(6) Involvement of bone.
(7) The degree and duration of distension of the joint cavity.

(1) and (2) are concerned with the general resistance of the individual, and, as already pointed out, fatigue, shock, and hæmorrhage greatly enhance infection.

The interval of time that elapses before treatment commences is very important, for up to a certain point the synovial membrane can successfully deal with infection. If, however, a high intra-articular tension be not early relieved, infection and toxæmia of a very grave nature will follow, death of the cartilages will be rapidly brought about, and at the best ankylosis must result.

A retained missile, with its piece of clothing, is a potent focus of infection. Sometimes the missile is lodged in that piece of bone which is intra-articular. In this situation it is not so serious a menace to the synovial cavity. There are many instances in which the missile has traversed the joint cavity and come to rest in the bone, infecting the latter structure, but not the joint cavity ; for the synovial membrane, by adhesions, has shut off the general synovial cavity from the track of the missile.

Severe damage to soft structures surrounding a joint and forming part of a penetrating wound is a serious source of infection, for not only

is there a large infected surface directly communicating with the joint cavity, but there is very often, in addition, severe damage to the arteries and nerves supplying the joint.

Injury to bone is a serious complication of all joint wounds from the point of view of infection and subsequent utility, for bone under these conditions is readily infected and very difficult to sterilise.

Pathology of Infected Wounds of Joints.

The question of infection in gunshot wounds of joints is dealt with in the chapter on wound infection, and is also considered in some detail in connection with gunshot wounds of the knee-joint. The general features may be restated.

1. **Resistance to Infection.**—The defensive powers possessed by joints against invading organisms appear to be very similar to those possessed by other serous membranes, such as the peritoneum, meninges, pleuræ, and pericardium. The resistance to infection in all such membranes is of high order. This is partly due to the character of the exudate which is so readily poured out in response to infection, and partly also to the anatomical structure of the membrane itself. The serous exudate is rich in antibodies and in actively phagocytic endothelial cells, and, in addition, it contains fibrinogen, which acts as a basis for plastic adhesion of the synovial surfaces at certain points. The living membrane of the joint is thus enabled to act in the same way as does the peritoneum when it shuts off infected foci by the formation of adhesions around them. While the range of mobility of the synovial membrane is naturally somewhat more restricted than that of the peritoneum, this action of localisation of infection is to some extent assisted by the rigid character of the synovial surface, whereby the division of the joint into pouches and loculi is rendered possible. These ridges are readily demonstrated in specimens in which the joint has been distended with formalin under pressure and sections made through the hardened tissues. Three or four of such ridges exist in the subcrureal pouch alone, and the other pouches of the joint are constructed on similar lines.

The loculation of the synovial membrane makes it possible for one or more pouches to be shut off from the general joint cavity. This condition actually occurs in certain cases of infection following penetrating wounds of joints. Examples of joint pouches which may be shut off in this way are, in the case of the knee-joint, the subcrureal and the posterior pouches (the latter by obliteration of the lateral channels formed by the reflection of the synovial membrane off the condyles of the femur). Thus, when infection invades a joint, the whole extent of the joint surface need not become involved, and in many cases the infection remains localised to one or more parts of the cavity. This is possible in a large number of gunshot wounds of joints, for in most of these, in the first

instance, the infection invades only a small part of the joint—*e.g.*, one or more of the anterior pouches, in the case of the knee-joint.

Conditions favouring Localisation of Infection within Joints.—These are—

(1) Perfect immobilisation of the joint.
(2) Reduction of the amount of exudate, if excessive.
(3) Injection of certain antiseptics—*e.g.*, ether.
(4) Complete closure of the wound in the joint capsule, so as to prevent continued access of infecting organisms from the outside.
(5) Fixation of the joint in such a way as to prevent spread of infective fluid by the action of gravity.

Most of these conditions are considered elsewhere.

(1) The first is self-evident; it admits of very wide application in connection with all foci of inflammation.

(2) It is obvious that though the arthritic exudate contains protective substances, an excessive bulk of fluid is bound to distend the whole joint and break down all barriers to the spread of infection. To obviate such a condition, aspiration of the fluid is indicated in these cases, wherever it can be carried out.

(3) Injection of ether, formalin and glycerin, and other antiseptics into infected joints has probably a harmful action upon the phagocytic cells as well as upon the organisms. The injection of ether has, however, three advantages: (*a*) It bubbles out through the wound in the capsule, thus showing clearly the position and extent of such wound; (*b*) in its exit from the joint cavity through the opening in the joint capsule it not improbably washes out infected material; (*c*) it evaporates and is absorbed with great rapidity, usually within a few minutes.

(4) This is an essential point in the surgical technique. If the aim is to prevent suppuration, the joint must be completely closed, in order to allow the complete defensive mechanism to act. Only if suppuration occurs should joints be treated by an open method.

(5) This refers, in particular, to the knee-joints, in which, with the patient in the dorsal decubitus, intra-articular fluid readily gravitates into the posterior pouches. The fluid tends to pass in the lateral synovial tracts extending from anterior to posterior pouches on each side. Unless the limb is in forcible extension, fluid does not pass between the bones into the posterior pouches, for the articular surfaces tend to remain closely apposed. Examination of many infected joints after amputation has clearly demonstrated this point. The method of fixation of the various joints is described elsewhere.

Suppuration within Joints.—Attention to the foregoing principles will in the majority of cases of penetrating wounds of joints, in which they can be carried out, result in complete subsidence of the infection,

the joint remaining a movable one. In a small minority of cases—in particular those in which a long-chained streptococcus has established its growth—the intra-articular inflammatory exudate will become purulent. If a joint exudate becomes frankly purulent (not merely turbid from increase of cellular content), it loses, among other things, its nutritive properties, on which the nutrition of the articular cartilage depends, and that important structure thus becomes devitalised. Both cartilage and synovial membrane are further acted upon by the locally produced toxins and organisms, and a certain amount of necrosis occurs. Necrosis of cartilage is liable to occur first at the line of junction of cartilage and bone, but may appear early in any part of the articular surfaces. It is followed by sloughing of pieces of cartilages, and these act as infected foreign bodies within the joint—that is, as a "nidus" for organisms. Sloughing of cartilage in time exposes cancellous bone, and may lead to necrosis of bone or even to septicæmia by entrance of organisms into the circulation in the bone. At the same time the endothelium of the synovial membrane becomes damaged; it becomes thickened and infiltrated with leucocytes, and gradually becomes converted into granulation tissue. Healing in such joints is bound to be accompanied by some degree of fibrous or osseous ankylosis. It is obvious, therefore, that when frank suppuration occurs within a joint, the joint cannot be treated by any closed method. It must be converted into an open wound and treated as such, and active sterilisation instituted in order to overcome the infection with a minimum loss of tissue and a consequent minimum disability.

Bacteriology of Gunshot Wounds of Joints.

This is considered fully in connection with gunshot wounds of the knee-joint, and the principal points only need be mentioned here.

Closed Joints.—The aspirated fluid, if such can be obtained, should be examined systematically as follows: (*a*) Physical examination; (*b*) examination of direct films; (*c*) cultural examination. The presence of a long-chained streptococcus either in direct films or in cultures is an indication for opening the joint and applying active measures of sterilisation. Occasionally, gas-producing anaerobes may be found in the fluid, but these, if active, are nearly always accompanied by streptococci. No bacteriological finding other than the presence of these two types of organisms is in our view sufficient indication for opening the joint.

Open Joints.—These are, for all practical purposes, open wounds lined by granulation tissue, and their bacteriology does not differ from that described for wounds in general.

Complications of Joint Injuries.

A. **Immediate Complications:**

(1) Acute infective arthritis.
(2) Acute infective periarthritis.
(3) Acute infective osteomyelitis.
(4) Septicæmia and pyæmia.
(5) The presence of other wounds complicating.
(6) Secondary hæmorrhage.
(7) Injury to large nerve trunks.

Acute Infective Arthritis has already been referred to. In complicated joints such as the knee this is an extremely grave complication, and often, in spite of active treatment, the result has been amputation, owing to the presence of grave toxæmia or threatening septicæmia.

Acute Infective Periarthritis results from extension of the infection either from the original wound in the periarticular tissues or from the joint cavity. Thus, an infected joint, through destruction of the continuity of its synovial membrane at any one point, may disseminate infection into the neighbouring muscular planes. Again, infection may travel along the sheath of an intra-articular tendon and give rise to an extra-articular abscess—*e.g.*, the biceps tendon in the case of the shoulder and the popliteus tendon in the case of the knee.

Suppurative periarthritis is most persistent and difficult of treatment when once established. It may involve tissues immediately adjacent to the great vessels of a limb, leaving them without support, and thus be the cause of a serious secondary hæmorrhage.

Acute Infective Osteomyelitis.—This grave complication is apt to follow the gross infection of a joint, especially the knee. Unless prompt amputation be undertaken, septicæmia and pyæmia, followed by the death of the patient, is the almost invariable result. Septic infarcts in the lung, with localised abscesses in the pleuræ and pericarditis, have been most constant in connection with osteomyelitis the result of war wounds, specially when the femur has been the bone in question. The medulla of the affected bone examined post mortem shows acute congestion, with beads of pus the size of a pin's head scattered irregularly and sparsely throughout its substance. The periosteum is congested and peels readily from the bone. The infection is usually mixed, but *Streptococcus pyogenes* has, in fatal cases, invariably been present. In no cases have we seen gas in the medullary cavity or gangrene of its contents.

Septicæmia and Pyæmia.—These fatal complications may be associated with infection of joints with or without osteomyelitis. The knee-joint is mostly to be feared in this connection, especially when infection is established in the posterior pouches. Abscesses may form in the lungs, in the

22

pleuræ, the kidneys, or the spleen. It is of interest that in cases dying from septicæmia as the result of war wounds we have not yet seen a case of endocarditis. The heart muscle shows fatty degeneration, and the liver is fatty to an extreme degree. The kidneys are congested, and often show multiple small abscesses. The causal organisms have in many instances been isolated from the blood-stream before death. Septicæmia and pyæmia vary in degree, and since employing the Carrel-Dakin system of wound treatment it is now fortunately of rare occurrence. During the sterilisation of an extensive compound fracture of the femur the patient may contract a pulmonary infarct, but the infection, owing to a continuous sterilisation of the wound and the consequent improvement in the general condition of the patient, has never proved of a serious nature.

A not uncommon accompaniment of septicæmia is a red, painful œdema in the neighbourhood of the large joints. The condition appears to be wholly periarticular, and flits from joint to joint, just as one sees in acute rheumatism. We have never seen one of these œdematous areas go on to suppuration. The condition at one time was so common that we designated it "migratory periarthritis."

On the other hand, abscesses may form beneath the skin in various parts of the body, the contents consisting of dirty-looking pus with broken-down, semi-digested tissue. Culturally the contents were, for the most part, sterile.

When septicæmia becomes established, the original wound presents an indolent aspect. The surface is dry and covered with a glairy mucoid material, and there is no wound secretion.

The Presence of Other Wounds Complicating.—Wounds of joints are seriously handicapped by the presence of other wounds complicating, especially if hæmorrhage to any extent has occurred from them. Should the joint condition be progressing well, the synovial cavity is very prone to become reinfected if other infected wounds be present. It is highly probable that in this case the infection is taken to the damaged joint via the blood-stream, for we have seen it occur in instances where every possible precaution has been taken in the dressing of these wounds. A wound of the thorax involving a lung militates strongly against the progress of wounds in other parts of the body, due, no doubt, to a less perfect oxygenation of the blood and an impaired heart's action. Wounds of other parts of the body which are complicated by wounds of the lung take longer to sterilise than similar wounds uncomplicated.

Secondary Hæmorrhage.—This is by no means an infrequent complication of large wounds involving the large joints, especially if bone is involved. It may occur from a large arterial trunk the result of periarthritic suppuration; it may originate from a fractured bone or from the arterial anastomosis surrounding the joint. Each hæmorrhage further lowers the general resistance, and so aids the spread of infection, both

locally and generally, for indeed, in this connection septicæmia has on more than one occasion followed upon a brisk secondary hæmorrhage. Fortunately, since the adoption of the Carrel-Dakin system this complication is now a very rare event.

Injury of Large Nerve Trunks.—In close relation to the large joints are the main nerves of the limb; consequently they are prone to injury. Foot-drop and wrist-drop should always be looked for, and necessary measures taken for their correction. Pressure sores must be guarded against and trophic conditions of the skin treated, should they occur. As soon as possible after sterilisation and suture of the wound measures must be taken to maintain the tone of the paralysed muscles. Rapid sterilisation and suture of these wounds is most desirable in order to reduce to a minimum the formation of scar tissue, with the consequent stiffness and adhesions in the muscles which follow in its wake.

B. **Remote Complications:**

(1) Stiffness and limited movement of the joint.
(2) Ankylosis.
(3) Deformity.
(4) Flail joint in cases where excision has been practised.

Stiffness and Limited Movement may either be intra- or extra-articular in origin. If intra-articular, the cause is most often due to adhesions. The adhesions with patience tend to stretch, and the range of movement will increase. In the case of men who are thirty years and over, the synovial membrane often remains thickened for some months after injury, and a degree of rheumatoid arthritis may ensue.

If the adhesions and fibrosis be extra-articular the case is more difficult, for muscles, nerves, and fascia may be all involved. The extra-articular structures in the case of wounds which have healed by secondary intention are welded together and involved in dense, unyielding scar tissue, which is often bound down to ligaments and bone. Increase in the range of movements is extremely slow and limited. The limitation of movement eventually becomes permanent, unless a subsequent operation be undertaken for removing the scar tissue and freeing the periarticular structures.

Ankylosis is the best result that can be obtained in some joints that have hopelessly suppurated. Many joints which have become infected and suppurated freely have been saved by the Carrel-Dakin treatment, provided the synovial cavity has not been obliterated. Thus, we have had instances of suppuration in the shoulder, ankle, and elbow joints, and yet these joints have completely recovered their function after sterilisation by the Carrel-Dakin method. Ankylosis may be either fibrous or bony, depending upon the degree of damage sustained by the articular cartilages.

Deformity results either from adhesions fixing the joint in a faulty position or from faulty ankylosis. Thus, if a knee-joint be allowed to

ankylose in a position of flexion, there will be a faulty transmission of body-weight, the limb will be shorter than its fellow, and further deformity will occur. Incapacity of a serious nature will also result when the joints of the upper extremity are allowed to ankylose in faulty positions.

Deformity is a late complication which falls to the lot of the orthopædic surgeon, and so will not further be discussed here. We would, however, urge that if proper measures be taken to sterilise a suppurating joint, other than the knee-joint, ankylosis will occur in only a very limited number of cases; for out of 300 consecutive cases of suppurating joints, other than knee-joints, treated by the Carrel-Dakin method, ankylosis occurred only in two.

Flail Joint results when an extensive excision has been undertaken owing to severe destruction of bone in the neighbourhood of a joint. We have personally seen very few such cases, for extensive excison has so rarely been necessary when joints have been sterilised by the Carrel-Dakin process, however fractured the bone may be. The wound has been sterilised in the usual way, and secondary suture performed. The results, on the whole, have been astonishing, as what seemed at first irretrievable damage has proved to be retrievable both as regards the limb and the joint. These cases have been followed through and their progress watched at an orthopædic depot. Damaged shoulder and elbow joints have especially surpassed all previous expectation.

The Hip-Joint.

Anatomical Considerations.—The hip-joint is of the ball-and-socket variety. Passing from a depression in the head of the femur to a depression in the floor of the acetabulum is the ligamentum teres. The synovial cavity is one large space interrupted only by the ligamentum teres, and postero-inferiorly the neck of the femur is in part intra-articular. The joint occupies a position in the wall of the bony pelvis, consequently wounds involving it are very apt to involve intrapelvic structures. The capsule of the joint is strengthened by the Y-shaped ligament of Bigelow anteriorly, whilst the pubo-femoral and ischio-femoral ligaments strengthen it on its inner and posterior aspects.

Closely related to this joint are the femoral vessels, the great sciatic nerve, the crucial anastomosis, and the external rotators of the thigh at the hip-joint.

Frequency of Occurrence.—Out of a series of 1,000 cases treated at a base hospital there were seven cases of injury involving the hip-joint. This gives a percentage of 0·7. This percentage is deceptive, for many cases of hip-joint injury, involving as they do the innominate bone and pelvic viscera, are rapidly fatal, and never reach a base hospital.

From a series of eighteen cases seen in the line, six reached the field ambulance, three of the six reached the casualty clearing station, and only

one of these three reached a base hospital. Thus, from one small series of eighteen cases there is the appalling death-rate of 94·5 per cent. Wounds involving the hip-joint are probably to-day as fatal as any. The series quoted refers to men wounded during quiet times in the line, when there was no undue rush of work, either at the field ambulance or casualty clearing station, and consequently at a time when more individual attention could be given. The series, again, occurred at a time when the Carrel-Dakin treatment was not being practised, but when drainage-tubes, salt, and the older antiseptics were in use.

Of the seven cases which reached a base hospital, three died, the cause of death being shock and toxæmia. Two died within seventy-two hours of admission; the third died a few days after admission from osteomyelitis of the innominate bone complicated by general septicæmia. It had been necessary in the last case to disarticulate at the hip-joint. The two cases which died within seventy-two hours of admission had both lain out, and arrived at the casualty clearing station suffering from an advanced gas-gangrene infection. The four cases that survived reached the casualty clearing station early, their wounds were immediately excised, and a Carrel-Dakin dressing applied.

Three of these four cases were completely sterilised, and healed after secondary suture at the end of the third week. At the end of one month from the date of injury these men were getting about well with the aid of crutches; the remaining case was up on crutches at the end of the twelfth week. This small series seen to the finish at a base hospital in the East, and differing in no respects from many cases seen and treated at a casualty clearing station in France, gives a recovery of 57 per cent. and an average stay in bed of five weeks. The end-result in each case was a movable joint soundly healed.

Nature of Hip-Joint Injury.—An injury of the hip-joint may involve—

(1) Bone.
(2) Periarticular structures.
(3) Intrapelvic or intra-abdominal viscera.

Bone.—The innominate bone or femur may be fractured either separately or in combination, the injury ranging from a clean perforation without comminution or loss of continuity to a breach of continuity with or without comminution. A clean perforation without comminution or loss of continuity is the result of rifle or machine-gun bullets, though these missiles may be responsible for the most extensive laceration of the soft parts and comminution of bone. A common sort of wound in this connection is one in which the great trochanter and neck of the femur have sustained a fracture communicating directly with the hip-joint.

Again, the missile may enter the head of the femur without causing a breach in continuity of bone (see Fig. 136).

More extensive wounds, the result of shell or a Minenwürfer, occur in which a large piece of the neck of the femur, with the great trochanter, may be pulverised or carried completely away, and on more than one occasion the lower extremity has been completely avulsed from the trunk through the hip-joint.

Dislocation of the hip has not been of infrequent occurrence during the present war. It has been the result of being buried in a dug-out, from being in the neighbourhood of an exploding Minenwürfer, and from aeroplane accidents. These dislocations are frequently associated with fracture of the upper and posterior borders of the acetabular cavity.

FIG. 136.—Shrapnel ball lodged in head of femur.

Again, soldiers with congenital dislocation of the hip are occasionally met with.

Periarticular Structures.—Wounds of the soft parts which also involve the hip-joint differ but little from wounds of the soft parts elsewhere. The wound of entry may be situated in the buttock, upper thigh, Scarpa's triangle, or in the immediate neighbourhood of the great trochanter. Wounds of the buttock are of a serious nature and very prone to gas infection, as also are wounds in the region of Scarpa's triangle. Wounds in the neighbourhood of the hip-joint are likely to involve such structures as the femoral, gluteal, and sciatic arteries, and the sciatic or other large nerves. The large arteries may be either completely severed, buttonholed, or contused, whereas the nerves may be contused, partially torn, or completely divided.

Intrapelvic or Intra-abdominal Structures.—A missile entering the pelvis after traversing the hip-joint may either come to rest in the extra-peritoneal connective tissues, or it may penetrate the peritoneum and inflict injury on the intrapelvic or intra-abdominal viscera. After penetrating the innominate bone, the missile carries in front of it not only its concomitant piece of cloth, but also spicules or plaques of the fractured bone. The intrapelvic lesion is not so much the result of the missile itself as of the piece of bone it carries before it. The pelvic viscera most frequently damaged in this connection are the bladder and rectum, though the small intestine and pelvic colon have been involved. In close relation to the acetabular

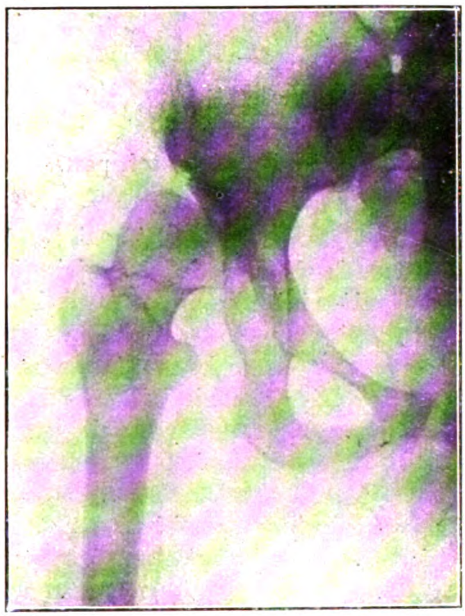


FIG. 137.—X-ray of soldier on active service who suffered from congenital dislocation of the hip.

cavity are the large intrapelvic vessels, which are undoubtedly ruptured in quite a number of these wounds, and this in all probability accounts for the sudden death in the line of men who have been hit in this region, for these men all died very rapidly, with symptoms of hæmorrhage.

COMPLICATIONS OF HIP-JOINT INJURIES.

A. **Immediate Complications** are—

(1) Shock.
(2) Hæmorrhage.
(3) Implication of pelvic or abdominal viscera.
(4) Other wounds complicating.

Shock of a severe degree is an invariable accompaniment of hip-joint injuries, especially if the sciatic nerve has been torn or divided.

Hæmorrhage may be slight or severe, visible or concealed. If smaller arteries only are divided, the shock occasioned by the injury causes a sufficient fall in the blood-pressure to prevent serious and immediate hæmorrhage. If, however, large trunks such as the femoral or iliac arteries are torn, then hæmorrhage is immediate, and in the latter case is nearly always rapidly fatal.

Implication of the pelvic and abdominal viscera has been already referred to. It may be added that such a complication calls for immediate laparotomy, which necessitates further shock and militates against the patient's chances of recovery.

B. **Remote Complications** are—

(1) Septic arthritis.
(2) Osteomyelitis.
(3) Infection of the soft parts.
(4) Septicæmia.

An open joint in contact with infected tissue is itself bound to become infected, and the danger in the case of the hip-joint is not so much the infection of the joint itself as infection of bone, and the spread of infection to the intrapelvic connective tissues.

Osteomyelitis may occur either in the femur or innominate bone, although in wounds involving the hip-joint the innominate bone has been the one of election. At a casualty clearing station a few cases of infection of the head and neck of the femur were seen, but the condition was far more frequent in the innominate bone. Osteomyelitis of the innominate bone is an exceedingly grave and fatal complication, as septicæmia is very prone to follow. Infection of the soft parts has been already dealt with.

Treatment.

A. **On the Battlefield.**—This consists in—

(1) Relief of pain.
(2) Arrest of hæmorrhage.
(3) Immobilisation of the joint.

Pain is best and quickest relieved by the administration of half a grain of morphia hypodermically. Any large bleeding-points must be clamped and tied, and a dressing applied to the wound. Particulars should be noted on the tally. The limb should be now immobilised at the hip-joint, and this is best accomplished by means of two rifles fastened together. The butt end of one rifle should occupy the axilla, and the butt of the second rifle be fastened to the boot. This done, the two legs should be fastened together with puttees, the wounded man given a warm drink, and sent on with as little delay as possible to the casualty clearing station.

B. **At the Casualty Clearing Station.**—When the patient is anæsthetised the temporary splint should be removed, together with all the clothing The pubes, perineum, and anus should be shaved, and also the skin both in the neighbourhood of the wound and at some distance from it. The skin around the wound is now thoroughly cleaned and disinfected and finally painted over with iodine. The wound must next be cleanly excised, and enlarged if necessary. After procuring absolute hæmostasis, a Carrel-Dakin dressing is applied and the limb put up in abduction with extension The most suitable apparatus for this is a Jones's abduction frame, and though transport with this is rather awkward, the difficulties are not insurmountable.

The patient is transferred to the base as soon as he is fit to travel, which is usually on about the third or fourth day.

C. **At the Base Hospital.**—The Carrel-Dakin treatment is continued until the dressing is changed, when smears are taken from every part of the wound and reported upon, the count of organisms per field being recorded on the temperature chart. It will be noticed that the joint cavity gradually shuts itself off from the exterior. The hole in the capsule becoming obliterated by plastic adhesions, which later are covered over with young granulation tissue. Provided the temperature keeps normal or is steadily falling, this event is one to be welcomed, for it is an indication that the joint cavity is sterile and shut off from the surrounding wound. When the bacterial count as obtained by smears shows 0·4 organism per field (2 to 5 fields), with healthy leucocytes and macrophages present, secondary suture may be safely performed. The stitches should be removed at the end of the tenth day, and if the wound is soundly healed the patient may get up on crutches. We have not always found it necessary to maintain abduction after the wound has soundly healed, as the patients can to some extent move the joint, and this should be encouraged. If, however, there has been fracture of the neck or great trochanter of the femur, or fracture of the acetabulum, especially of the upper lip, then extension and abduction must be maintained. For this reason, after the wound has soundly healed, the patient can be put up in plaster with the limb abducted and slightly externally rotated at the hip-joint.

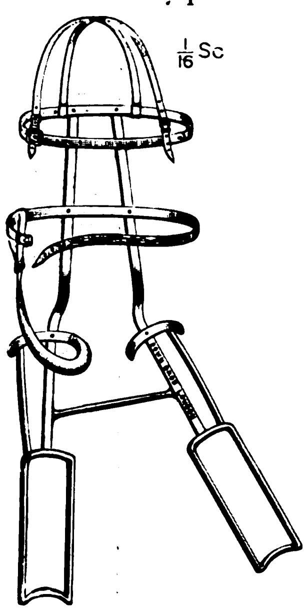


FIG. 138.—Jones's abduction splint, for fractures through the hip-joint and just below the trochanter.

Should the sciatic nerve or branches of the anterior crural nerve be divided, they should be sutured prior to performing secondary suture of

the wound, and all necessary steps must be taken to guard against foot-drop and trophic sores. Patients suffering from wounds of the hip-joint often complain for the first few days of severe pain in the knee. This troublesome symptom is purely a referred pain, and passes off as the wound about the hip becomes sterile. Aspirin (gr. x.) given three times a day is usually sufficient to give the patient complete relief.

The Knee-Joint.

Anatomical Considerations.—Developmentally the knee-joint consists of three pouches—one superior and two lateral, the latter separated by the ligamentum mucosum. Accessory pouches later join the main cavity; thus, the subcrureal bursa becomes attached from the third to the

Fig. 139.—Medial section through knee-joint.

Note the subcrureal pouch, divided by irregular septa, communicating with the suprapatellar pouch. The ligamentum mucosum divides the suprapatellar and infrapatellar pouches, and the infrapatellar pad of fat intervenes between the infrapatellar pouches and the bursa beneath the ligamentum mucosum. The posterior pouch has been opened to show its extent and the level of reflection of the synovial membrane posteriorly.

fifth year, and the posterior bursa joins up anywhere from the tenth to the fourteenth year. The posterior bursa is divided mesially by the posterior crucial ligament, and joining its internal division is the bursa beneath the semimembranosus tendon. A bursa beneath the ligamentum patellæ sometimes communicates with the main cavity. The adult knee-

joint thus consists of a subcrureal pouch, paired lateral suprapatellar pouches, paired lateral infrapatellar pouches, a posterior pouch completely divided in the middle line, the semimembranosus bursa, and sometimes the bursa beneath the ligamentum patellæ—that is, nine pouches in all.

Anteriorly the synovial membrane is pushed forwards by the infrapatellar pad of fat and forms the ligamentum mucosum. Inferiorly the line of reflection is along the upper margin of the tibia, whilst superiorly

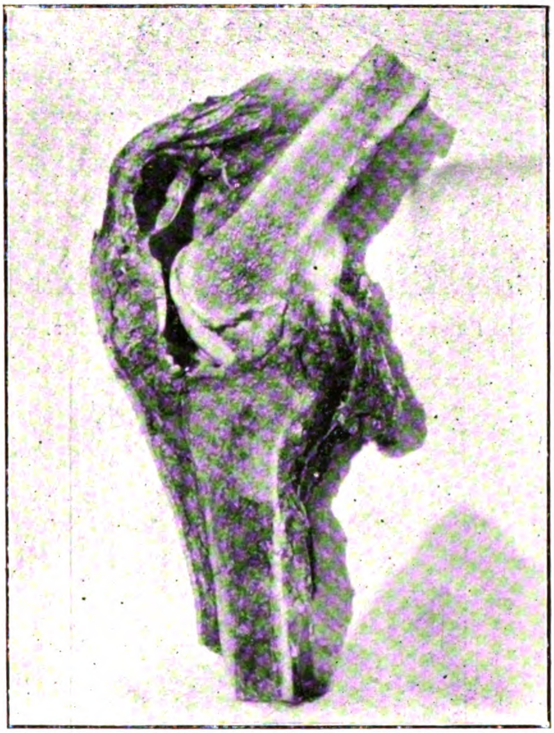


FIG. 140.—Section through knee-joint.

Note partition formed by the crucial ligament, dividing the posterior pouch completely into two. Note also the septum in the subcrureal pouch. The ligamentum mucosum has been removed.

it is at the apex of the subcrureal pouch. Laterally the line of reflection is about the same level as the anterior margins of the internal and external lateral ligaments, and posteriorly it is situated along the upper margin of the tibia below and above the femoral condyles above.

The communication between the anterior and posterior pouches, so far as spread of infection is concerned, is around the lower aspect of the condyles of the femur, where a narrow channel exists which is formed by the reflection of the synovial membrane.

FIG. 141.—Dissection to show posterior bursa.

FIG. 142.—Section of knee-joint with patella turned back to show the line of reflection of the synovial membrane from the femoral condyle.

This is the route of communication between the anterior and the posterior pouches.

The posterior pouch is easily and readily obliterated by slightly flexing the knee and applying very light pressure over the popliteal space, and the lateral communications between the anterior and posterior pouches are also easily obliterated by very slight pressure.

The subcrureal pouch is irregularly divided by a series of septa, whereas the reflection of the synovial membrane laterally presents a scalloped appearance.

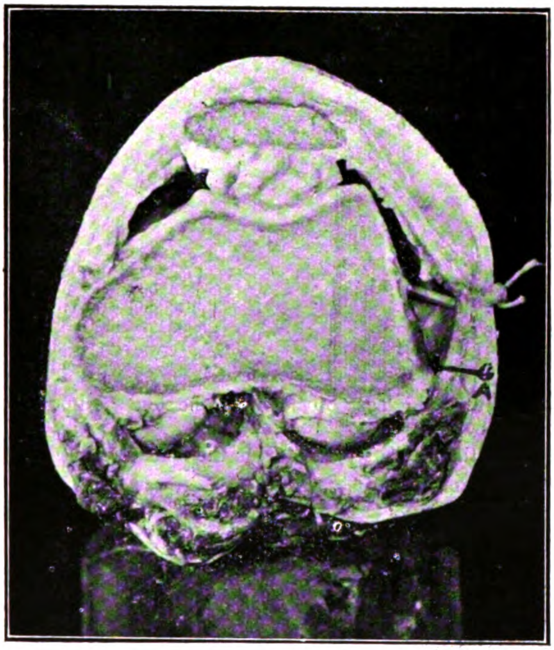


FIG. 143.—Transverse section through knee-joint, showing posterior and lateral pouches, with the route of communication between them.

On the right of the figure the lateral pouch is propped open and an arrow marked *A* shows the track of communication. Note the level of the lateral reflection is that of the anterior margin of the lateral ligaments.

Running through the outer aspect of the posterior bursa is the popliteus tendon. Closely related to the joint posteriorly are the popliteal vessels and nerves, while a rich arterial anastomosis surrounds the joint and the patella.

Frequency of Occurrence.—From nearly 2,000 consecutive cases of gunshot injuries treated at a base hospital there have been 115 cases of knee-joint injuries. This gives a percentage of 5·7. During active fighting, when advancing troops are going forward in the face of machine-gun fire, the percentage is probably higher. Many men who are hit in the knee-joint die from other injuries on the battlefield or at the clearing station, and for this reason statistics of a clearing station are more reliable than those of a base hospital, though, of course, the most reliable statistics

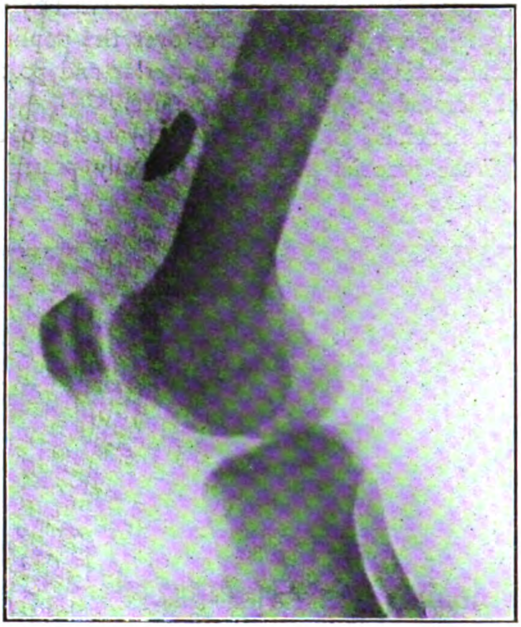


FIG. 144.—Large piece of high explosive lying in the subcrureal pouch after chipping the bone.

Note the patella separated from the femoral condyles.

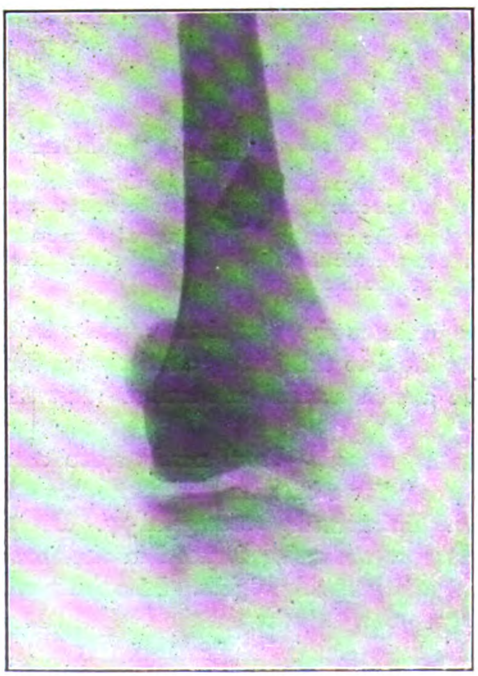


FIG. 145.—Same case viewed antero-posteriorly.

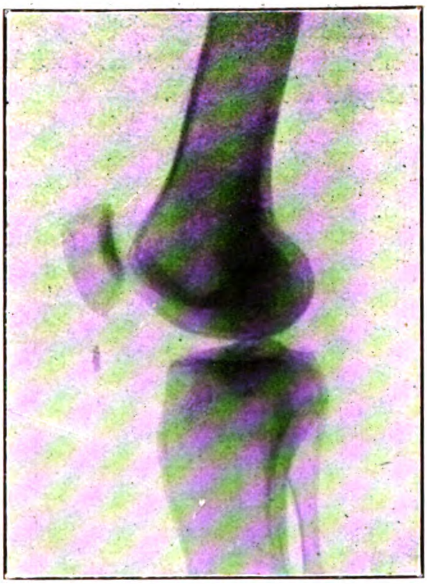


FIG. 146.—Small piece of high explosive lodged in the ligamentum patellæ. Knee-joint contained fluid.

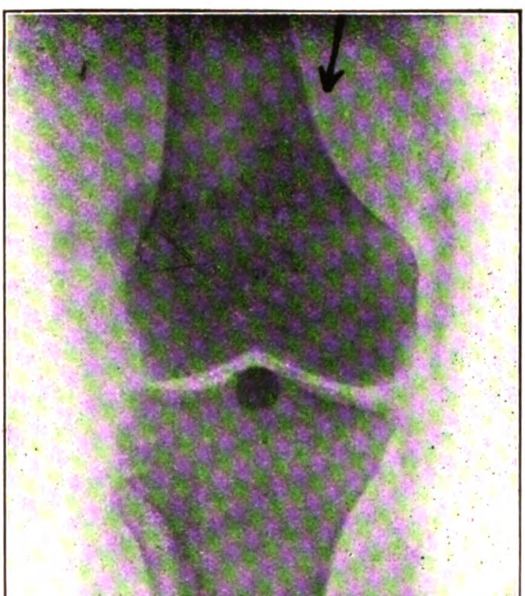


FIG. 147.—Bullet passed downwards and backwards through femur, and stopped in centre of head of tibia. Removed through transverse incision.

are regimental when taken from a number of regiments. During active fighting, from rough calculation we would say that gunshot injuries of the knee-joint form fully 8 per cent. of all wounds, probably more if many enemy machine-guns are in action.

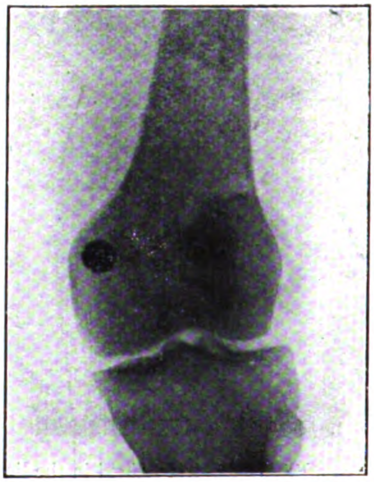


FIG. 148.—Shrapnel ball lodged in condyle of femur.

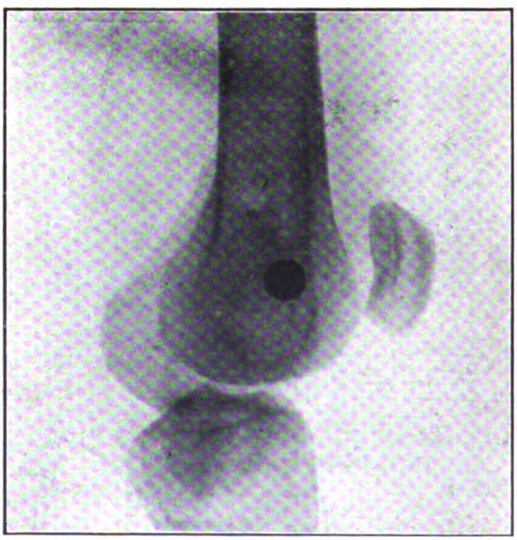


FIG. 149.—Same case as Fig. 148, but viewed laterally.

Nature of the Injury.—Wounds of the knee-joints may be—(*a*) Penetrating, (*b*) Perforating, and they may or may not involve bone.

Penetrating wounds of the knee-joint may be caused by rifle bullets, shrapnel balls, or small pieces of high explosive. The foreign body may

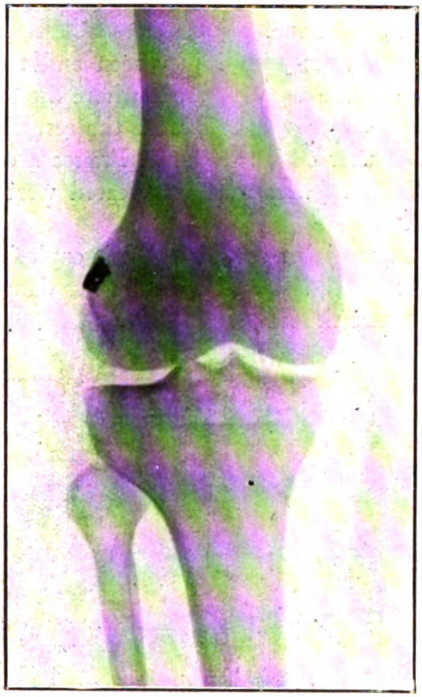


FIG. 150.—Piece of high explosive lodged in condyle of femur.

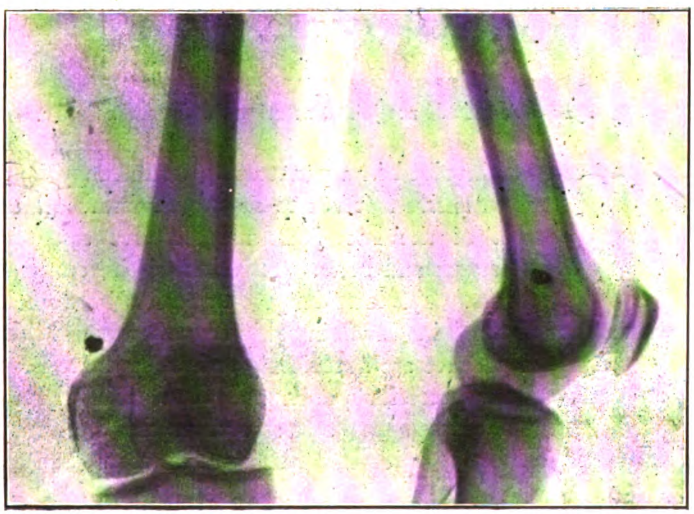


FIG. 151.—Piece of high explosive which penetrated the knee-joint and came to rest in the periarticular tissues.

come to rest either in the joint cavity, the ligamentum patellæ or peri-articular structures, or in bone.

From 115 cases of knee-joint injury seen and treated by us in the Balkans we have not seen a single instance where the missile used has been a rifle bullet; all, without exception, were the result of shrapnel or high explosive. This is rather odd, because in France a considerable proportion of the knee-joint injuries that we treated were caused by rifle or machine-gun bullets.

Wounds of the knee-joint caused by high explosive are undoubtedly the most dangerous of all, shrapnel balls are less dangerous, and rifle and machine-gun bullets are the least dangerous.

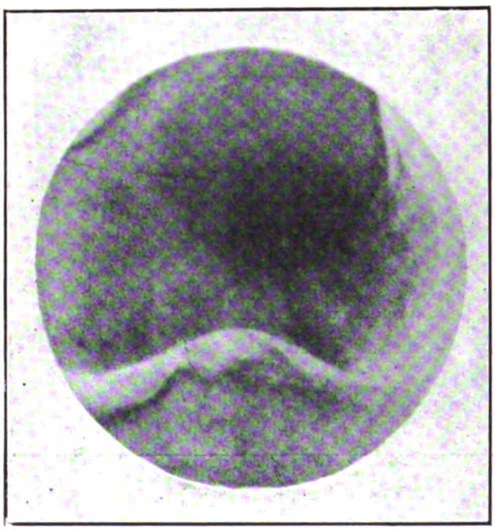


FIG. 152.—Wound of knee-joint fracturing the femoral condyle.

The injury to bone involved in a penetrating wound may range from a perforation without extensive fracture to excessive comminution.

Perforating wounds of the knee-joint may involve soft structures only or both soft structures and bone. The sites of the entry and exit wounds are of importance. The least dangerous seem to be wounds about the anterior aspect of the joint involving only the anterior pouches, while wounds in the popliteal space are notoriously serious, as there is both the risk of infection of the posterior pouch and damage to the popliteal vessels and nerves. The damage to soft structures and bone may range from a simple perforation to laceration and comminution of an extensive kind.

A knee-joint may become involved as the result of a fissured fracture of the femur communicating with the joint cavity. In this case a hæm-arthrosis results, which may or may not become infected.

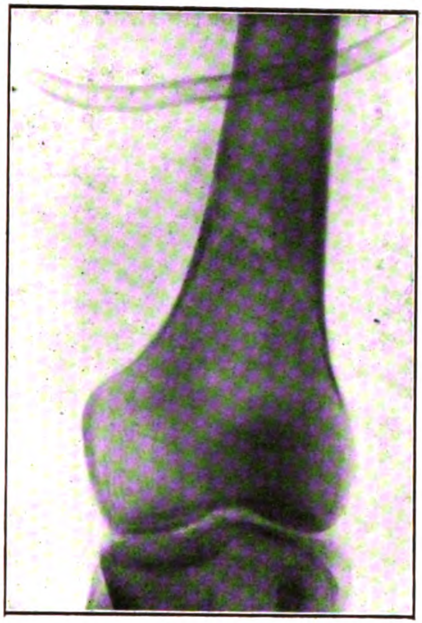


FIG. 153.—Fracture of femur giving rise to a hæmarthrosis of the knee-joint.

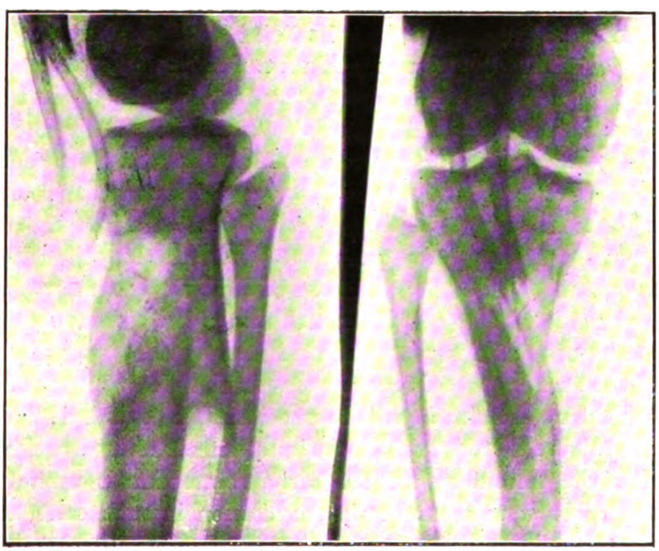


FIG. 154.—Severe fracture of upper end of tibia communicating with the knee-joint.

Gunshot wounds of the knee-joint may damage the popliteal vessels or nerves, especially if the wound be situated in the popliteal space. It is interesting to note that in this connection the external popliteal nerve is by far the most frequently involved, and dropped foot results.

Again, infection may travel from the joint cavity through the original perforation in the synovial membrane, and give rise to periarticular suppuration, which is apt to result in secondary hæmorrhage. Provided that intra-articular tension be kept low by aspiration, the synovial membrane can deal with a considerable degree of infection if the joint be kept absolutely at rest.

The periarticular structures in the immediate neighbourhood of the wound are contused and œdematous ; consequently, any extension applied to such a wounded limb is painful and militates against complete rest of the wounded joint.

Should fracture of bone have occurred, infection is very likely to follow, either of a limited or diffuse type.

Bacteriology.

In considering the question of infection in knee-joints following gunshot wounds, it is desirable to discriminate between three main classes of injury :

I. Wounds in which a part of the joint is laid *widely open*.
II. Wounds in which the opening in the joint capsule is small.
III. Wounds in which the joint capsule is unbroken.

I. Wounds in which a Part of the Joint is laid Widely Open.—Many of these wounds require amputation at the casualty clearing station, but a fair proportion are treated by conservative methods, and reach the base hospital with the limb preserved. They are usually the result of wounding by high explosive or by explosive bullets, and are accompanied in most cases by considerable loss of bony substance. The cases which come under treatment at the base hospital are generally those in which a single joint pouch is widely opened up. In such cases the remainder of the joint commonly becomes shut off, and from the point of view of infection the wound does not differ materially from a compound fracture. The material secured for examination is simply the discharge from the depths of the granulating surface of the wound, unless the rest of the joint becomes filled with fluid, in which case a simple aspirated fluid may be obtained. Where there is much loss of substance, healing is a slow process, and, unless the wound be sutured early, reinfection is prone to occur. It is often difficult to secure early sterilisation in such cases, unless the technique throughout has been faultless ; where sterilisation is delayed, when the Carrel-Dakin method has been used the dominant organism is found to be a long-chained streptococcus (Fig. 9, p. 43). Autogenous vaccines in large doses are recommended for such cases.

FIG. 155.—Route of infection from anterior to posterior pouches.
The director is placed in the path of spread of infection around the lower aspect of the femoral condyle.

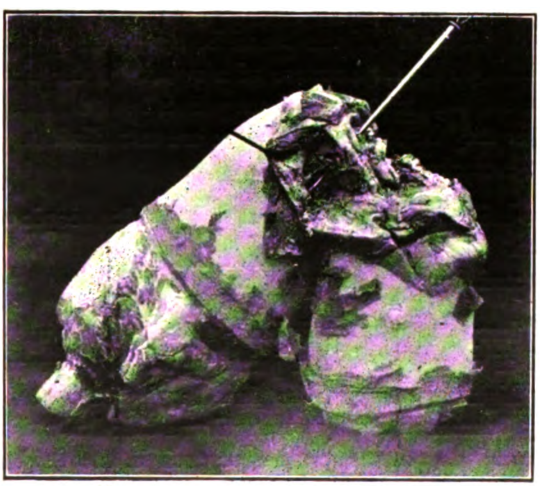


FIG. 156.—Route of spread of infection from anterior to posterior pouches marked with director (lateral view).

II. **Wounds in which the Opening in the Joint Capsule is Small.**—This class forms the large majority of gunshot wounds of the knee-joint. The material obtained for bacteriological examination is the fluid aspirated from the joint at the commencement of the application of the dry treatment. Such aspirated fluid may be obtained either at the casualty clearing station or at the base hospital, or both. The fluid may come from a single shut-off pouch, the subcrureal, or it may be a sample of the general synovial exudate of the joint. The object of the bacteriological examination is—

(1) To ascertain the presence or absence of established infection.
(2) To ascertain the type of infection.
(3) To prepare a vaccine, if necessary.

Both (1) and (2) have a definite relation to prognosis and treatment, as will be seen later, and (3) is now recognised as a valuable subsidiary form of treatment in suitable cases.

The examination of the knee-joint fluid falls under three heads :

(1) Physical.
(2) Direct films.
(3) Cultures.

(1) **Physical Examination.**—The following types of fluid, classified according to their physical characters, may be seen :

(1) *A Fluid containing Non-Hæmolysed Blood mixed with Synovia.*—In nearly all cases of penetrating gunshot wounds of joints, if the fluid be aspirated before actual suppuration occurs within the joint, the fluid is found to be blood-stained. Where the joint capsule has not been penetrated (a point which is, at times, difficult to determine), the joint fluid is usually not blood-stained. If the blood be not hæmolysed, it may, in a few cases, be derived from puncture of a vessel by the needle. This is likely to be the case where the blood coagulates in the tube. Apart from such accident, it may be stated that there are two distinct types of fluid containing non-hæmolysed blood :

(*a*) Non-infected fluids, as shown by microscopic and cultural tests.
(*b*) Infected fluids, as shown by the same tests.

In a series of forty-two aspirated knee-joint fluids, type (*a*) was met with in six, all of these being from joints in which the capsule had been penetrated by high explosive. The fluid, aspirated at least three days after the injury, contained simply uncoagulated blood mixed with synovia ; direct films showed no polynuclear leucocytosis in the fluid and no tissue elements indicative of repair ; cultures were sterile. The examination of the fluid revealed no sign of gross inflammatory change within the joint. Since fragments of high explosive carry infection into the tissues in practi-

cally every case, it must be presumed that any infection which may have been introduced had been satisfactorily overcome by the vital activity of the synovial membrane—in other words, that the infection had not become established. All of these cases had been treated by the dry method, and immobilisation had been thorough. In most of them the technique of treatment described elsewhere in this chapter had been carried out, although in some it had been incompletely performed. The fact, however, that fluids of this type are met with in such a proportion of cases seems to point to high powers of vital resistance to infection on the part of the synovial membrane of the knee-joint.

Type (*b*) was obtained in nine out of the forty-two fluids. All of these were from penetrating wounds of the knee-joint. In three cases the evidence of infection was unequivocal, *Staphylococcus aureus* being grown from the fluid. In the other six cases the fluid was sterile on culture, but there was seen in direct films a definite excess of polynuclear cells, as compared with normal blood. This "leucocytosis of the joint," as we have called it, we have come to regard as sufficient evidence of infection, even in the absence of growth in cultures. The type of infection in these nine fluids was thus one which was non-hæmolytic to blood. *Staphylococcus aureus*, when present alone, has never been observed to hæmolyse the blood. The staphylococcus cases, as well as those in which cultures yielded no growth, apparently, therefore, constitute a non-hæmolytic type of infection which is relatively a mild one. In every case in this series the dry treatment was sufficient to overcome the infection. The temperature remained elevated for a very few days as a rule, and swelling and pain rapidly subsided. In not a single case did the infection go on to suppuration, and the cases were regularly dismissed to the convalescent depot with movable joints at the end of six weeks. Since we know from experience that *Staphylococcus aureus* is capable of producing acute suppuration in the knee-joint under other less favourable methods of treatment, it seems probable that the dry method of treatment employed has some beneficial effect in aiding the synovial membrane to overcome this type of infection.

(2) *A Fluid containing Hæmolysed Blood mixed with Synovia.*—Hæmolysis in these fluids varies considerably in degree. Its presence is determined by a permanent reddish tinge in the supernatant fluid obtained after centrifuging the specimen or allowing it to stand. All grades of colour may be seen, from a slight tinging of the supernatant fluid to a deep red colour.

In sixteen out of the forty-two aspirated fluids examined by the authors, hæmolysis was present, and in eleven of these, organisms were found in direct films or on culture. In the remaining five cases no organisms were found, but a definite polynuclear leucocytosis of the joint was obtained in all. The infection in this series was generally much more serious than where the infection was non-hæmolytic. The most common infecting organism

found was *Streptococcus pyogenes*, and other varieties of streptococci were also cultivated.

We regard hæmolysis as an important point to be observed in the aspirated fluids from wounded knee-joints. Hæmolysis always indicates infection, and the infection is often of a severe type.

(3) *A Yellow Fluid with a Coagulum.*—This is the ordinary serofibrinous exudate of a serous membrane reacting to irritation, whether infective or mechanical. It is obtained in certain penetrating wounds of the joint in which no gross hæmorrhage has occurred into the joint—*e.g.*, where foreign bodies are very small, and also in certain non-penetrating cases where there is acute inflammation in the neighbourhood of the joint. The depth of tint varies from a deep straw to a lemon-yellow colour, and is probably due to the presence of blood-pigment. This pigment is, in most cases, locally produced from slight extravasation of blood in the exudate, but it may be associated with a yellow colour in the serum generally resulting from hæmolysis in the circulating blood. This is seen, for example, in cases where an effusion occurs into the knee-joint during the course of severe gas-gangrene toxæmia. Fibrinogen is usually present in considerable amount in these yellow-coloured fluids. Out of six fluids of this class in our series, four were from penetrating wounds and two from non-penetrating wounds of the joint. The four from the penetrated joints were all infected, the organisms grown being a short-chained streptococcus, *Staphylococcus aureus*, and a diphtheroid bacillus. The remaining two fluids, one of which was straw-coloured and the other lemon-yellow, yielded no evidence of septic infection, no leucocytosis of the joint, and no growth on culture was obtained. In both of these cases the wound was a severely infected compound fracture of the lower third of the femur, just above the joint. The case from which the straw-coloured fluid was obtained was a fatal gas-gangrene wound. In the five of these cases which recovered, the infection within the joint, indubitably present in four, was sufficiently mild to subside completely under the dry method of treatment properly carried out. Not one case progressed to suppuration. The conditions of infection appear in these cases to be similar to those obtaining in a simple serofibrinous exudate of pleura, peritoneum, or pericardium, all of which, in general, subside completely when the parts are kept at rest.

(4) *A Flaky Coagulated Non-Pigmented Fluid.*—This type is rare, only two cases out of the series of forty-two having been seen by the authors. Both of these cases were from penetrating wounds of the joint, and both were infected. One of them yielded *Streptococcus fæcalis* on culture. In both cases the joint infection subsided under the dry method of treatment.

This kind of fluid appears to be present in certain penetrating wounds of the knee-joint where no hæmorrhage has occurred into the joint—*e.g.*, in cases of penetration by multiple minute fragments of high explosive.

It is associated with a type of infection mild enough to be overcome by the joint synovial membrane when the latter is put under the proper conditions.

(5) *A Fluid containing Pus.*—This type of fluid occurred in nine out of our series of forty-two early aspirated fluids. Almost all occurred among the first lot of knee-joints treated, when the treatment at the casualty clearing stations, as well as elsewhere, was faulty. All of them were aspirated and found to contain pus within the first three or four days after the infliction of the wound. In all cases the infecting organism was found to be a long-chained streptococcus, which was proved on several occasions to be *Streptococcus pyogenes.*

The amount of pus varied much, and in some cases was sufficient to produce only a slight turbidity in the fluid. *In every case, however, it was found necessary to treat the joint by the open wet method.* The joint synovial membrane is apparently unable to subdue, unaided, a well-established infection with *Streptococcus pyogenes.*

It was amongst the first twenty cases of this series of forty-two that eight of the nine cases with purulent fluid occurred. In the last twenty-two cases only one was found, and in this case the gross error of leaving the capsule of the joint unsutured had been committed at the casualty clearing station. The greatly diminished incidence of this severe form of infection in the later joints treated was ascribed entirely to improved technique of operation and subsequent treatment. The infection is one which would appear to be preventable by proper early application of the dry method of treatment described. When the infection is once established, the dry treatment is inadequate, and the joint must be opened and vigorous antiseptic irrigation treatment carried out.

Odour.—The discharge from infected knee-joints has rarely any foul odour. The aspirated fluid as well as the ordinary discharge from widely opened joints may contain gas-forming anaerobes—the former somewhat rarely, the latter commonly. Both *B. perfringens* and *B. sporogenes* have been frequently cultivated from knee-joint fluid. It is rare, however, to detect a foul odour in the fluid, and actual gas-formation within the joint is seldom, if ever, seen. The joint synovial membrane, like other serous membranes, such as the peritoneum, meninges, and pericardium, appears to have more active powers of dealing with anaerobic infection than has muscle or fascia.

2. **Examination of Direct Films.**—Direct films are made from the fluid or from its centrifuged deposit, and stained by Kühne's carbol-methylene blue and by Gram's method. As a rule, it is sufficient to make the film from the fluid as received, but where the fluid is almost clear, the cellular elements being scanty, it is desirable to centrifuge 1 c.c. or more of the fluid in a narrow tube and make films from the deposit.

Carbol-methylene blue, as previously stated, is an excellent stain for the purpose, and has the following advantages :

(*a*) Cells are well stained, and differentiation between nucleus cytoplasm is marked.
(*b*) Organisms are stained intensely and sharply.
(*c*) Red blood-corpuscles are stained green, and can thus be distinguished at once from lymphocytes and tissue cells.
(*d*) Certain leucocytes are stained purplish (both polynuclears and mononuclears); these invariably show a widely meshed nuclear chromatin, and not uncommonly organisms are seen in their cytoplasm. Their significance is unknown, but their appearance and incidence suggest that the purplish colour denotes some degree of exhaustion or degeneracy, possibly associated with phagocytosis.

The points of practical importance to be noted in the examination of direct films are—

(1) The types and relative numbers of cells present.
(2) The presence or absence of organisms, and, if present, their nature.

(1) As regards the cellular elements, the most important point is to determine whether there is a relative excess of polynuclear cells, as compared with normal blood, when blood is present in the exudate. A glance at the film under the microscope is usually sufficient to determine this, but occasionally a rough differential cell count is necessary. Where the excess of polynuclears is definite, a "polynuclear leucocytosis of the joint" is present, and this we regard as evidence of active infection, even when other tests are negative. When the fluid does not contain blood, the presence of even a few polynuclears is abnormal and indicative of some degree of septic infection.

The large mononuclears, both large lymphocytes and endothelial cells, are commonly present in fair numbers, as in all serous exudates, and this point must be allowed for in estimating "polynuclear leucocytosis of the joint." When tissue cells are present in quantity they denote an ulcerative or granulating condition of the synovial membrane or other structure within the joint.

The presence of organisms is usually clearly shown both in the blue-stained film and in the Gram preparation. The presence of large, stout, Gram-positive bacilli usually denotes gas-forming anaerobes. If present, they are to be regarded as a sign of danger, but their mere presence is no indication for special treatment, such as opening the joint, unless they are accompanied by long-chained streptococci. The organism which we have found to be of most serious import is *Streptococcus pyogenes*, which appears in direct films in long-chained form. Wherever a long-chained streptococcus is found in numbers in the exudate of wounds, whether open or closed, the sterilisation of the wound is not proceeding satisfactorily,

and in general, further or more efficient treatment is required. In every case in which we have found a long-chained streptococcus in direct films from joint fluid, the dry treatment alone has failed, owing to the severe toxæmia or septicæmia which has been produced; in all such cases the joint has been opened and Carrel's procedure applied, and in some cases the limb has later been amputated. This bacteriological finding we regard as sufficient indication in itself for opening the joint. The infection, in our experience, is not always a virulent one. Clinically the joint is acutely swollen and tender, and there are symptoms of severe toxæmia. But even if symptoms be less acute, we regard the above finding as sufficient to indicate immediate treatment of the joint by the open wet method.

Coliform bacilli, etc., are usually seen in direct films only in the case of gross infection, in which case streptococci are not likely to be present in addition. If unaccompanied by a long-chained streptococcus, they denote active septic infection, but the joint must not necessarily be opened.

3. **Cultural Examination.**—Both aerobic and anaerobic cultures should be made, and in general the principles of cultivation of wound bacteria already mentioned (pp. 72-80) should be followed.

Cultures from knee-joint exudates may be of practical importance in at least two ways: (*a*) They determine definitely the type of infection present, a point which is of interest and may be of assistance to the surgeon in determining further treatment; and (*b*) they may be required for the preparation of autogenous vaccines. Such vaccines should be employed, in particular, in all infections with *Streptococcus pyogenes* or other virulent streptococcus. Aerobic cultures should be made on an enriched protein medium such as trypagar or brain agar. Primary anaerobic cultures should be made, both in milk under paraffin to test for *B. perfringens*, and also in broth, preferably of a kind containing particles in suspension—*e.g.*, egg broth or brain broth. Subcultures may be made upon Dorset's egg medium for *B. sporogenes*, and on glucose-agar plates, incubated anaerobically by some such method as Henry's (p. 79), in order to obtain pure cultures, if such are desired. The following scheme is suggested for cultural examination:

Incubation.	*Media for Primary Culture.*	*Media for First Subculture.*	*Media for Subsequent Subcultures.*
Aerobic	Trypagar or brain agar.	Brain agar (for vaccines).	Brain agar (for vaccines).
Anaerobic	1. Milk under paraffin.	Milk after heating to 80° C. for 20 minutes.	Dorset's egg medium.
			Glucose-agar plate.
		Alkaline meat.	
	2. Broth or egg broth or brain broth.	Alkaline meat or glucose-agar plate.	Glucose-agar plate.

Aerobic Cultures.—Any of the aerobes of wounds may be isolated. The most common are staphylococcus, *Streptococcus pyogenes*, *Streptococcus fæcalis*, or the enterococcus, *Micrococcus tetragenus*, and coliform and diphtheroid bacilli. The *Streptococcus pyogenes* infections are the worst. They not uncommonly occur in joints which have been badly treated —*e.g.*, where a joint has been washed out with saline, or where the capsule has not been closed. The presence of this organism forms the only absolute bacteriological indication for opening the joint and treating by the Carrel-Dakin method. Infection with any of the other aerobes can usually be subdued by the synovial membrane, if the joint be treated from the outset as described in the section on Treatment.

Anaerobic Cultures.—The most common organisms isolated are *B. perfringens* and *B. sporogenes*, the chief representatives of the saccharolytic and of the proteolytic groups of anaerobes respectively. They are usually found in wounds in which the joint is widely opened and there is free communication with the surface. They are sometimes cultivated, however, from the aspirated fluid from a closed joint. Although these anaerobes are cultivated from the joint with comparative frequency, actual gas-formation within the joint is rarely, if ever, seen. This fact also lends support to the view that the knee-joint synovial membrane, as regards resistance to infection, is no less active than other serous living membranes —*e.g.*, those of the peritoneal and pericardial cavities, in which gas-formation is the greatest rarity (p. 143).

III. **Wounds in which the Joint Capsule is Unbroken.**—Effusion may occur into the knee-joint in case of certain non-penetrating wounds involving structures in the immediate neighbourhood of the joint—*e.g.*, compound fractures of femur and tibia, or any gas-gangrenous wound in the vicinity of the joint. On account of this it is sometimes difficult to determine whether the capsule has been penetrated or not, and in such cases the method of injection of ether into the joint from the opposite side of the wound, as described on p. 369, is of particular value in settling this point. In these non-penetrating wounds the fluid aspirated from the joint is not usually blood-stained, and is generally either a yellow serofibrinous exudate or a frankly purulent fluid, depending on whether the extra-articular pus has invaded the joint capsule or not. The methods of examination of the fluid and of treatment of the joint do not differ from those already described.

Delayed Infection of the Knee-Joint comes under this heading. The term is applied to those somewhat rare cases of compound fracture of the femur or tibia in the neighbourhood of the joint which are followed by a sudden effusion into the joint at a period averaging some two to three weeks after the infliction of the wound. The path of the infection is usually a fissured fracture of the bone, although the fissure is not always demonstrable in a radiogram. The infecting organisms, which are usually virulent streptococci, travel along the fissure in the bone to the joint during the latent period.

When the joint infection does occur, therefore, it is not uncommonly a virulent streptococcal one, and the condition generally is to be regarded as serious.

The diagnosis of the type of infection and the treatment are on the lines already described.

Spread of Infection within the Joint.—The evidence afforded by the morbid anatomy of amputated specimens as to the routes of spread of infection within the knee-joint has been already dealt with (pp. 335 and 347).

Summary.—1. In certain penetrating wounds of the knee-joint the infection carried in by the missile fails to produce inflammatory changes under appropriate methods of treatment. The fluid aspirated from the joint in such cases is mixed blood and synovia only, without hæmolysis; direct films show no polynuclear leucocytosis, and cultures are sterile.

2. The following physical characters of aspirated fluids from the knee-joint denote established active infection: (*a*) Hæmolysed blood, (*b*) flakes, (*c*) pus. If non-hæmolysed blood be present, the fluid may yet be infected, but a non-hæmolytic type of infection is generally less severe than a hæmolytic type.

3. Direct films giving a polynuclear leucocytosis in the joint fluid indicate infection, even when cultures yield no growth.

4. Of all the organisms which may be cultivated from aspirated knee-joint fluids, a *long-chained streptococcus* is the only one which consistently fails to be subdued by the vital resistance of the synovial membrane under appropriate dry methods of treatment. The presence of this organism in films or cultures is a direct indication to open the joint and apply wet methods of treatment. The joint fluid in such cases, if aspirated after the second or third day, is usually found to be purulent.

5. If the fluid aspirated after the third day be non-purulent, the joint inflammation should, in general, subside under the dry method of treatment.

6. The rarity of gas infection within the knee-joint, in spite of the frequent presence of gas-producing anaerobes, supports the view, based on this and on the other facts noted above, that the knee-joint synovial membrane has powers of vital resistance comparable to those possessed by the peritoneum and other serous membranes.

7. In certain non-penetrating wounds effusion may occur into the knee-joint. The aspirated fluid in such cases may or may not be infected, and the treatment depends on the bacteriological findings, as indicated above. Where the effusion occurs in bone cases many days after the infliction of the wound (delayed infection), the fluid usually contains a virulent long-chained streptococcus, and indicates a serious infection requiring wet methods of treatment.

The appended table shows the bacteriological findings, the treatment, and results of treatment, in a consecutive series of gunshot wounds (high

TABLE SHOWING BACTERIOLOGICAL FINDINGS, TREATMENT, AND RESULTS IN A SERIES OF GUNSHOT WOUNDS OF THE KNEE-JOINT.

KNEE-JOINT FLUIDS ASPIRATED AFTER THIRD DAY.

Case.	Bacteriology.									Treatment.		Results.			
	Physical Characters.					Direct Films.		Cultures.							
	Blood and Synovial Fluid.	*Hæmolysis.*	*Yellow Exudate.*	*Flakes.*	*Pus.*	*Polynuclear Leucocytosis.*	*Organisms.*	*Aerobes.*	*Anaerobes.*	*Dry Method.*	*Wet Method.*	*Movable Joint.*	*Stiff Joint.*	*Amputation.*	*Death.*
1	+	–	–	–	–	+	–	*Staph. aur.*	–	+	–	+	–	–	–
2	+	–	–	–	–	+	–	*Staph. aur.*	–	+	–	+	–	–	–
3	+	–	–	–	–	+	–	–	–	+	–	+	–	–	–
4	+	–	–	–	–	+	–	–	+	–	+	+	–	–	–
5	+	–	–	–	–	–	–	–	–	+	–	+	–	–	–
6	+	+	–	–	–	+	*Diplococci*	*long strep.*	–	–	+	–	–	+	–
7	+	+	–	–	+	+	*long strep.*	*long strep.*	–	–	+	–	+ ?	–	–
8	+	+	–	–	+	+	*long strep.*	*long strep.*	–	–	–	–	–	+	–
9	+	–	–	–	–	+	–	–	–	+	–	+	–	–	–
10	+	+	–	–	+	+	*long strep.*	*long strep.*	–	–	+	–	+ ?	–	–
11	–	–	+	–	+	+	*Diplococci*	*short strep.*	–	+	–	+	–	–	–
12	+	+	–	–	+	+	*Diplococci*	*long strep.*	–	–	+	+	–	–	–
13	–	–	–	–	+	+	–	*long strep.*	–	–	+	–	–	+	–
14	+	+	–	–	–	+	*Diplococci*	*short strep.*	–	+	–	+	–	–	–
15	+	+	–	–	–	+	–	–	–	+	–	+	–	–	–
16	+	–	–	–	–	–	–	–	–	+	–	+	–	–	–
17	+	+	–	–	–	+	–	–	–	+	–	+	–	–	–
18	–	–	–	–	+	+	*long strep., etc.*	*long strep., etc.*	+	–	+	–	–	–	+
19	+	–	–	–	–	+	–	–	–	+	–	+	–	–	–
20	+	+	–	–	+	+	*long strep.*	*long strep.*	+	–	–	–	–	+	+
21	+	–	–	–	–	+	–	–	–	+	–	+	–	–	–
22	–	–	+	–	–	–	–	–	–	+	–	–	–	–	+*
23	+	–	–	–	–	–	–	–	–	+	–	+	–	–	–
24	+	–	–	–	–	–	–	–	–	+	–	+	–	–	–
25	+	+	–	–	–	+	–	–	–	+	–	+	–	–	–
26	+	–	–	–	–	–	–	–	–	+	–	+	–	–	–

* Gas gangrene.

Case.	Bacteriology. Physical Characters. Blood and Synovial Fluid.	Hæmolysis.	Yellow Exudate.	Flakes.	Pus.	Direct Films. Poly-nuclear Leucocytosis	Organisms.	Cultures. Aerobes.	Anaerobes.	Treatment. Dry Method.	Wet Method.	Results. Movable Joint.	Stiff Joint.	Amputation.	Death.
27	+	+	−	−	−	+	−	−	−	+	−	+	−	−	−
28	+	+	−	−	−	+	*Diplococci*	*short strep.*	−	+	−	+	−	−	−
29	+	+	−	−	−	+	−	−	−	+	−	+	−	−	−
30	+	+	−	−	−	+	−	+	−	+	−	+	−	−	−
31	−	−	+	−	−	+	*Diplococci*	*Staph. aur. and diphtheroid*	−	+	−	+	−	−	−
32	+	+	−	−	−	+	−	*short strep., etc.*	−	+	−	+	−	−	−
33	−	−	−	+	−	+	−	*short strep.*	−	+	−	+	−	−	−
34	−	−	+	−	−	+	+	+	−	+	−	+	−	−	−
35	−	−	−	+	−	+	−	−	−	+	−	+	−	−	−
36	+	+	−	+	−	+	+	*short strep.*	−	+	+	−	−	−	+
37	+	−	−	−	−	+	−	−	−	+	−	+	−	−	−
38	+	+	−	−	−	+	−	+	−	+	−	+	−	−	−
39	−	−	−	−	+	+	*long strep.*	*long strep.*	−	−	+	−	−	+	−
40	+	−	−	−	−	+	+	+	−	+	+	−	−	+	−
41	+	+	−	−	−	+	−	+	−	+	−	+	−	−	−
42	−	−	+	−	−	−	−	−	−	+	−	+	−	−	−

PURULENT EXUDATES FROM WIDELY OPENED KNEE-JOINTS.

Case.	Blood and Synovial Fluid.	Hæmolysis.	Yellow Exudate.	Flakes.	Pus.	Poly-nuclear Leucocytosis	Organisms.	Aerobes.	Anaerobes.	Dry Method.	Wet Method.	Movable Joint.	Stiff Joint.	Amputation.	Death.
1	−	−	−	−	+	+	+	+	+	−	+	−	−	+	−
2	−	−	−	−	+	+	+	+	−	−	+	−	−	+	−
3	−	−	−	−	+	+	+	+	−	−	+	−	−	+	−
4	−	−	−	−	+	+	+	+	−	−	+	−	−	+	−
5	−	−	−	−	+	+	+	+	+	−	−	−	−	+	+
6	−	−	−	−	+	+	+	+	+	−	+	−	−	−	+
7	−	−	−	−	+	+	+	+	+	−	+	+	−	−	−
8	−	−	−	−	+	+	+	+	−	−	+	−	−	+	+
9	−	−	−	−	+	+	+	+	+	−	+	+	−	−	−
10	−	−	−	−	+	+	+	+	−	−	+	+	−	−	
11	−	−	−	−	+	+	+	+	+	−	+	+	−	−	−
12	−	−	−	−	+	+	+	+	−	−	+	−	+	−	−

explosive) of the knee-joint bacteriologically investigated. It will be observed that, generally speaking, the best results are found in the later cases of the series, when technique had become more perfect.

Treatment.

A. **On the Battlefield.**—The wounded joint must be absolutely immobilised in a position of very slight flexion. A piece of ration box with a pad made from a puttee placed beneath the popliteal space is all that is required. After application of the first field dressing, the wounded man should be carried with as little delay as possible to the advanced dressing station. A quarter of a grain of morphia may be given hypodermically to relieve the pain, and this must be noted on the regimental tally, with the date and hour of the wound.

B. **At the Field Ambulance.**—Should immobilisation of the injured joint be complete and satisfactory, nothing further need be done at this unit beyond administering the usual dose of antitetanic serum. If, on the other hand, the splint applied on the battlefield is inadequate, then a back splint with foot-piece, with a pad in the popliteal space, must be substituted, and the patient sent on to the casualty clearing station without delay.

C. **At the Casualty Clearing Station.**—On arrival at this unit the injured joint is usually acutely swollen, tender, and fluctuant. The advisability or not of performing a complete operation at this unit depends upon the presence or not of a reliable X-ray apparatus, and whether or not an undue rush of work is going on. Should the unit be not unduly pressed, and should it be in possession of a pathologist and a good X-ray apparatus, then operation may advisedly be undertaken. On the other hand, should the conditions be adverse, then simple aspiration only of the joint is advisable, for undue risk is taken in opening a knee-joint in an operating-theatre where operations for other severely infected wounds are in progress. After aspiration of the joint contents and the consequent immediate relief of the intra-articular tension, the joint is immobilised by means of a back splint and foot-piece and two side splints, slight flexion being maintained and pressure exerted both posteriorly and laterally by means of suitable pads. Prior to aspiration the limb in its entirety must be thoroughly washed and shaved, and the skin made as sterile as possible. We have latterly in the East also shaved the pubes, perineum, and anus in every case, as under the circumstances it is more cleanly and makes the nursing more simple. At a busy casualty clearing station in France we practised simple aspiration of the joint in a large number of cases. After aspiration the cases were immediately evacuated to the base, and subsequent information from the base hospitals proved the practice both sound and justifiable. Reports from the base hospitals seemed to prove conclusively that better results

followed simple aspiration at the casualty clearing station, whereas reports on joints that had been opened and washed out with saline, with or without removal of a foreign body, were unsatisfactory, and we can strongly corroborate this from our experience at a base hospital in the Balkans; for out of a series of sixteen knee-joint injuries in which joint lavage had been practised after excision of the wound, twelve progressed to a most virulent suppurative arthritis; whereas in a series of thirty-one cases, all the result of high explosive, that had been treated by simple aspiration at the casualty clearing station, only one case became infected. This is a striking difference.

D. **At the Base Hospital.**—At this unit an X-ray should be taken in two directions as soon as after arrival as possible, in order to determine any bony damage and the presence of a foreign body. If the joint is acutely distended it should be aspirated at once, and the contents sent to the bacteriologist for investigation. A microscopical report aids greatly in prognosis and the subsequent treatment of the case. Favourable signs in the joint-fluid are the presence of a leucocytosis in which the leucocytes are healthy and stain well, absence of organisms in a smear preparation, and the presence of a few organisms either in smear or culture, provided the *Streptococcus pyogenes* is absent. A very unfavourable sign is the presence of a turbid fluid containing small flakes of lymph, and microscopically showing degenerate leucocytes and the presence of *Streptococcus pyogenes*.

If a foreign body be present in the joint, it is important to ascertain from the patient the posture he was in at the time of being wounded—*e.g.*, was he sitting, crouching, standing, etc.—because the foreign body is invariably more easily extracted with the joint in the degree of flexion or extension that obtained when the wound was inflicted.

Operation.—The patient is fully anæsthetised before the splint and dressings are removed, and throughout the operation the greatest care must be taken not to move the joint unless it is absolutely necessary, as by this means infection is only further disseminated. The limb should be again thoroughly cleaned with ether soap, followed by biniodide of mercury in spirit, dried, and the joint painted over with iodine. An aspirating needle is now inserted into the opposite side of the joint to that of the wound, the joint contents removed and sent in a sterile tube to the bacteriologist (see Figs. 157, 158). The needle is left in the joint, and through it 5 c.c. of ether are injected into the joint cavity; the needle is then removed. The joint now becomes swollen and tympanitic, owing to the vaporisation of the ether. The wound is then seared over either with pure carbolic or the cautery, this precaution being taken to avoid any weeping from the septic wound surface on to the cleanly excised wound. If the cautery be used instead of pure carbolic, it should be before the injection of ether. The wound is finally excised *en masse*, including the perforation in the capsule. Prior to excision of the wound a tourniquet is applied to the limb. The wound throughout the operation is swabbed with 1 in 1,000 saline solution of flavine or brilliant green, or with eusol.

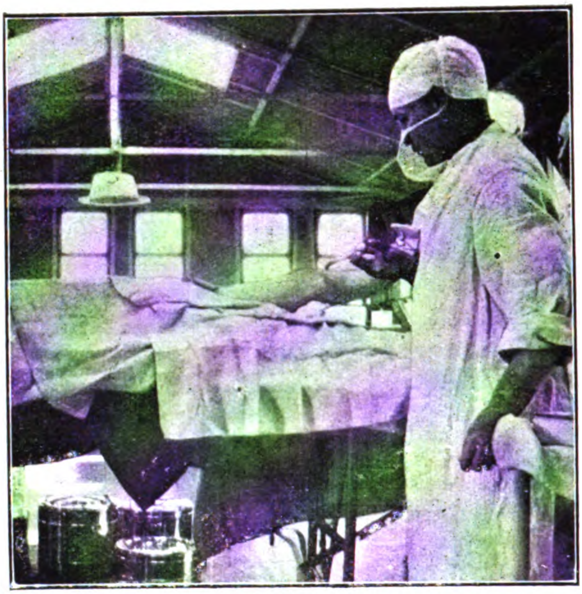


FIG. 157.—Wound on outer side of left knee-joint. Aspiration performed on inner side.

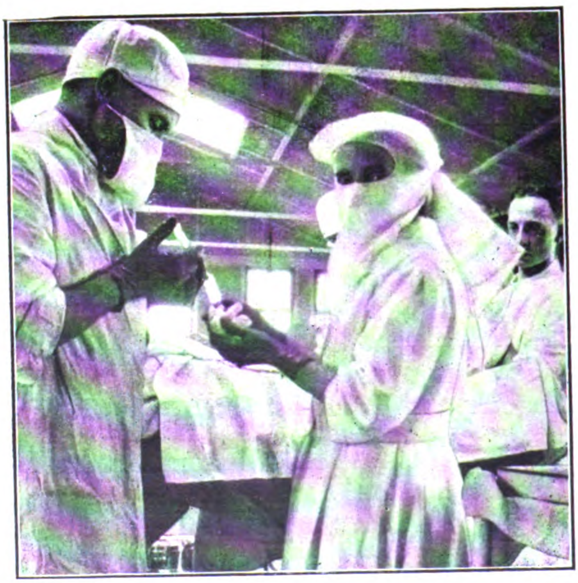


FIG. 158.—Emptying contents of knee-joint into a sterile test-tube for bacteriological examination.

As soon as the ether is injected into the joint, it is seen to bubble out of the wound in the capsule. This is of advantage, as it shows exactly where the perforation in the capsule is situated and its extent, while at the same time the constant ebullition of ether from the hole in the joint

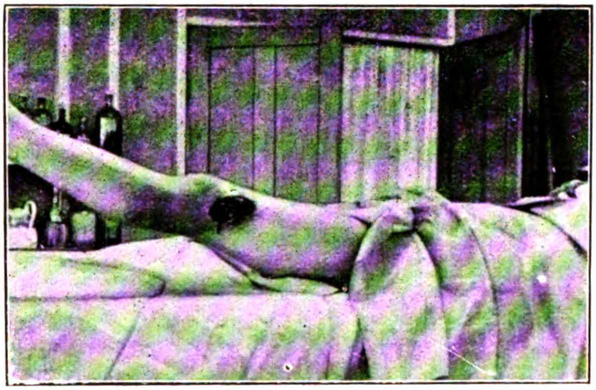


FIG. 159.—Wound of knee-joint after excision.

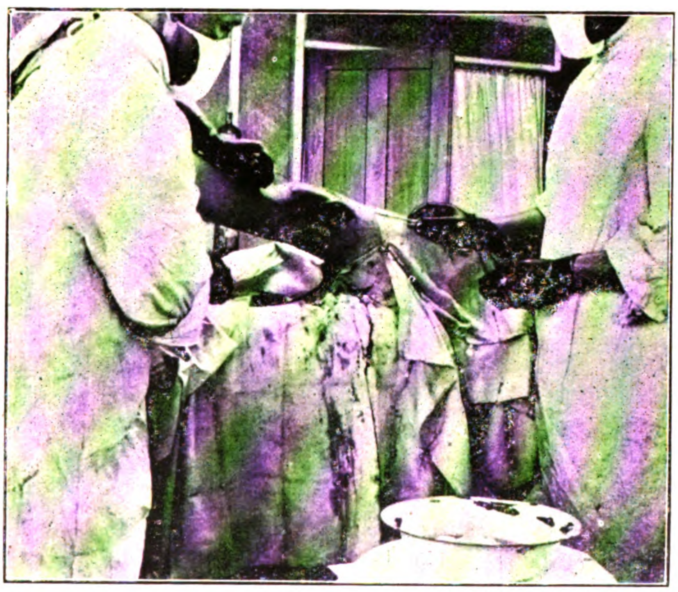


FIG. 160.—Closure of the hole in the capsule with a continuous suture of catgut.

prevents, to a large degree, the entrance of infection during the process of excising the wound. Moreover, on more than one occasion the missile has been forced out of the hole in the joint capsule by the force of the ether behind it.

After the wound is excised the surgeon changes his gloves, and uses fresh instruments and towels.

If necessary, the incision in the capsule is now enlarged in order to

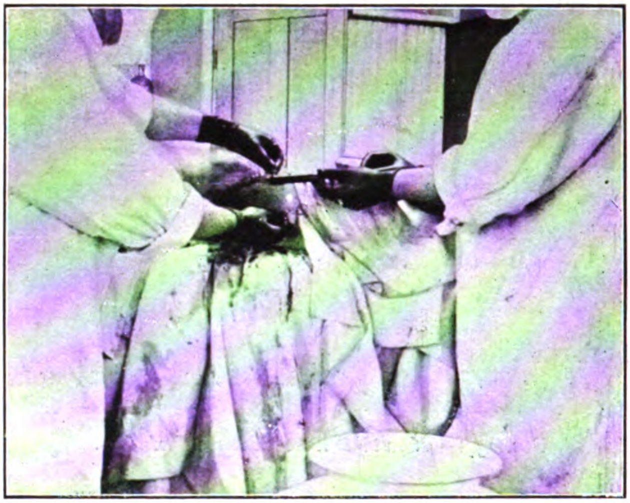


FIG. 161.—Injection of flavine or brilliant green into skin wound before tying off the last skin suture.

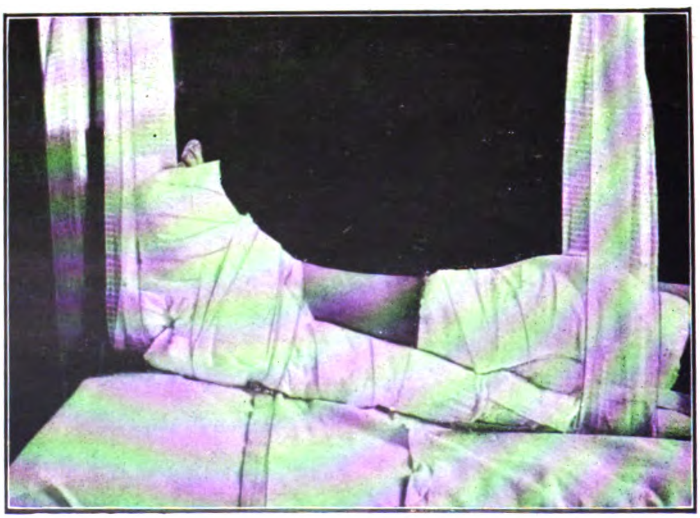


FIG. 162.—Firm bandage applied and joint immobilised on a back-splint and footpiece in slight flexion with a pad placed in the popliteal space.

expedite the removal of the foreign body, though this is not often called for.

The next step is closure of the hole in the synovial membrane and

capsule with a continuous catgut stitch. The surgeon can be sure that the hole is satisfactorily closed when the ebullition of ether ceases. *The joint is not washed out* (see Fig. 160).

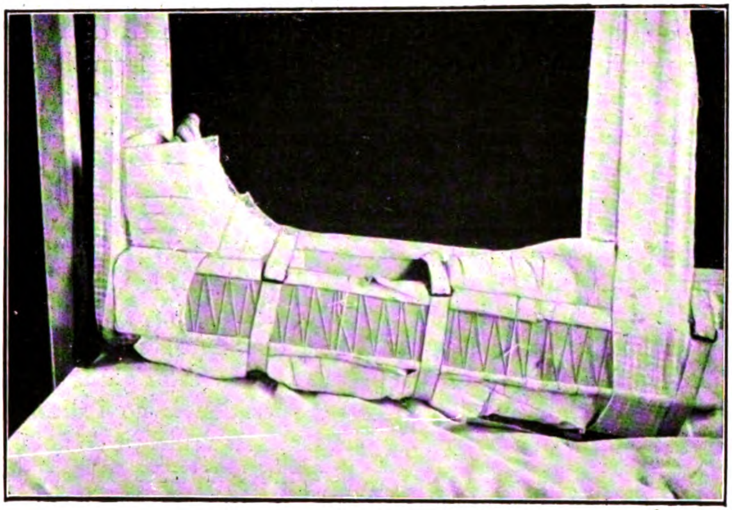


FIG. 163.—Same case with lateral splints applied and limb suspended just free of the bed by means of a Balkan support.

FIG. 164.—Two cases of severe injury of knee-joint complicated by extensive fracture of the upper end of the tibia two months after injury.

Both cases are getting about with full range of flexion and extension.

Finally the skin wound is closed with interrupted sutures of silkworm-gut. Before tying the last skin suture 1 or 2 drachms of flavine or brilliant

green (1 : 1,000 solution) are injected into the wound and included (see Fig. 161).

A dressing and firm bandage are now applied, the tourniquet is removed, and the limb is put upon a back splint and foot-piece with lateral splints, a pressure-pad being placed in the popliteal space to obliterate the posterior pouch, and lateral pads to occlude the route from the anterior to the posterior pouches. The limb is then slung just free of the bed and is suspended from a Balkan support (see Figs. 162, 163).

After-Treatment.

The joint at the end of twenty-four hours is distended, but not painfully so. At the end of forty-eight hours the distension is less, and after four or five days there is no fluid to be detected in the joint, and by this time the temperature is usually normal. The joint is kept absolutely immobile for three weeks, the stitches being removed on the eighth day. The reactionary fluid in the joint following operation is no indication for further interference in the form of aspiration. As a rule, we do not disturb the dressing for four or five days unless the temperature keeps unduly high.

Fig. 165.—Extensive wound of knee-joint in which patella was torn back. Full range of movement and patient walking two months after injury.

At the end of three weeks gentle massage is commenced, and the patient is allowed up on crutches with the joint still immobilised.

FIG. 166.—Three cases of penetrating wounds of knee-joint five weeks after infliction of wounds.

The man on the extreme right of the picture sustained wounds of both joints. All wounds caused by high explosive. All cases walking with full range of movement.

FIG. 167.—Four cases of gunshot wounds of the knee-joint five weeks after infliction. All wounds caused by high explosive. Patients about and walking with good movement.

Gentle movements are commenced at the end of a month, and the patients are allowed to walk.

At the end of the fifth or sixth week full range of movement has returned, and the patients are discharged to a convalescent depot.

Of thirty-one consecutive cases of knee-joint injury treated by the method recommended above, in which the joint fluid without exception showed infection to be present, only one case progressed to suppuration. The remaining cases were up and about at the end of the sixth or seventh week, and there was no need for them to leave the country.

The whole treatment aims at putting the joint under the best conditions to cope with what infection remains. This scheme of treatment

FIG. 168.—Group of six severe knee-joint injuries the result of high explosive. The photograph was taken four weeks after injury. The man with the amputated leg sustained injuries to both knee-joints.

is based upon the careful examination of early failures, for every joint was most carefully investigated after amputation in order to see where any mistake lay. It was found that infection of the posterior pouch was the invariable bugbear, and we now think that its prevention is possible if the wound does not originally involve the posterior aspect of the joint. By obliterating the posterior pouches and the route of infection from the anterior to the posterior pouches—and this we have, after several experiments performed post mortem, found both possible and simple—infection may be limited and arrested. To sum up :

(1) Relieve intra-articular tension at the earliest possible moment.
(2) Excise the wound *en masse* and remove the foreign body.

(3) Close the perforation in the synovial membrane and capsule.
(4) Close the wound in the skin, including an antiseptic.
(5) Slightly flex and absolutely immobilise the joint.
(6) Obliterate the posterior pouches by a pad placed in the popliteal space.
(7) Obliterate the lateral communications between the anterior and posterior pouches by lateral pads.
(8) Sling the limb on a Balkan support.
(9) Don't be in a hurry to aspirate if the joint becomes distended after operation; always be guided by the temperature and pulse. One need only have apprehensions if the bacteriologist reports the presence of *Streptococcus pyogenes* in the aspirated fluid.
(10) Be scrupulously aseptic.

When once the knee-joint has progressed to a suppurative arthritis, and especially if *Streptococcus pyogenes* be present, then it must be opened, and no small incision will suffice. Lateral incisions must be employed which will enter the joint cavity at the level of the lateral reflections of the synovial membrane, and must extend from top to bottom of the synovial cavity (see Fig. 169).

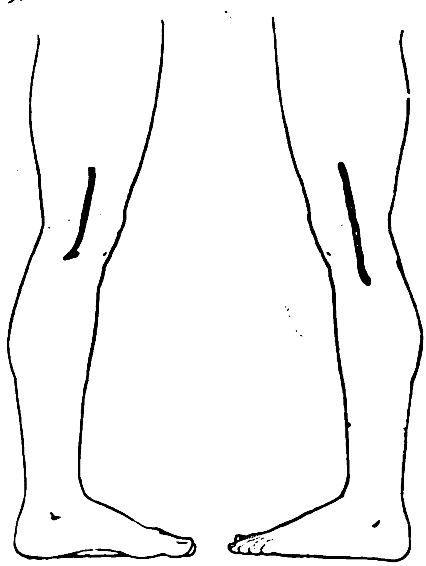


FIG. 169.—Line of incisions for opening knee-joint for extensive suppurative arthritis The line of incision runs along the level of the lateral reflections of the synovial membrane.

It is useless to make the incisions farther forward, as by this means a sump is left in which pus stagnates.

The posterior pouches must next be opened, and this is best accom-

plished by thrusting a large pair of Spencer Wells or sinus forceps backwards along the route of communication between the anterior and pos-

Fig. 170.—Incisions on posterior aspect of joint for gaining access to the posterior pouches.

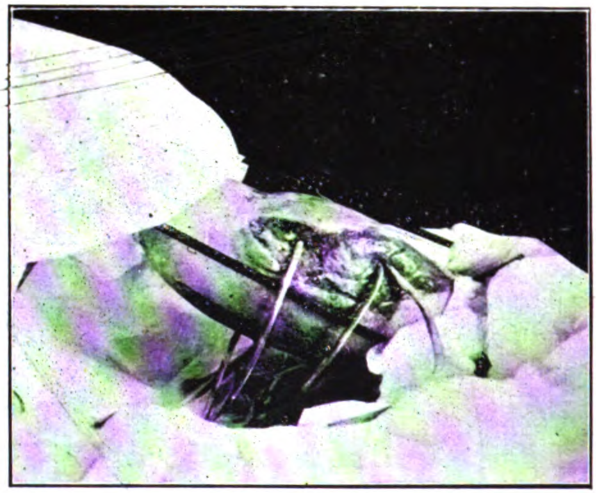


Fig. 171.—Suppurative arthritis of the knee-joint undergoing treatment by the Carrel-Dakin method.

Note lateral and posterior incisions.

Fig. 172.—Suppurative arthritis of knee-joint undergoing treatment by the Carrel-Dakin method.

Note lateral and posterior incisions.

terior pouches until their points can be felt beneath the skin, and then cutting down on to them. After washing out the entire joint, first with

saline and then with eusol, Carrel's tubes are introduced, four anteriorly and two posteriorly, and the limb is put up on a Thomas's knee-splint with extension. A dressing is then applied, and hourly instillations of the hypochlorites are carried out. When once the joint has progressed to this degree of infection ankylosis is almost inevitable ; hence a stiff joint must be aimed at (see Figs. 171, 172).

If in spite of treatment suppuration is still going on, or if suppuration has become extra- or peri-articular and secondary hæmorrhage be likely, or if, as is usually the case when infection of the posterior pouches has occurred, septicæmia be threatening, and especially if large serious wounds complicating exist, then amputation should be performed.

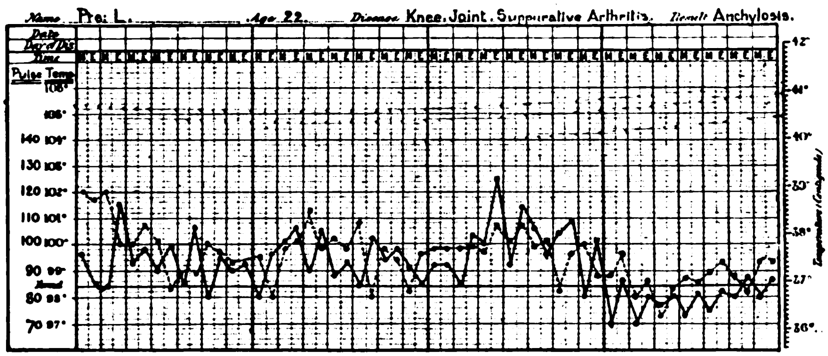


FIG. 173.—Suppurative arthritis of knee-joint treated by method recommended.

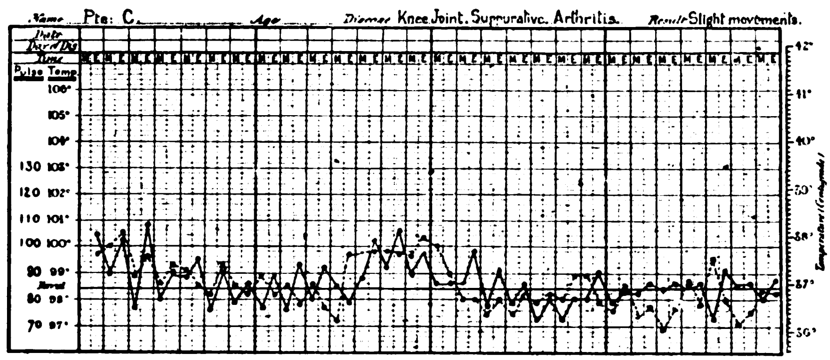


FIG. 174.—Suppurative arthritis of knee-joint treated in manner recommended.

If the missile be lodged in bone in such a position that its extraction may add to the risk of causing a suppurative arthritis, it is best left alone, for it can always be extracted later, when the knee-joint has recovered. We have adopted this practice in several cases, and seen no reason to regret it, as infection of the joint from the presence of a foreign body in the bone has not occurred—at any rate as late as the end of the third month after injury.

If, on the other hand, the foreign body is easily accessible and can be removed without risk, this should always be done.

If bone is severely fractured, treatment will depend upon the conditions actually present. Should the patella be the bone involved, and should it be very comminuted, then it is best to remove it altogether.

If the articular ends of the tibia and femur are comminuted, then the choice of operation lies between excision or amputation.

We have performed excision in a small number of cases, but abandoned the practice, as our results did not justify the procedure.

Amputation is indicated in the following conditions:

(1) Excessive comminution of bone involving more than 3 inches of continuity.
(2) Septic arthritis or periarthritis which is threatening to progress to septicæmia.
(3) Wounds of a severely lacerated type in which the main artery and nerves have been irretrievably damaged.
(4) Severe secondary hæmorrhage the result of periarticular sepsis.

Out of a series of 115 cases of knee-joint injury, all of which were, without exception, the result of high explosive and shrapnel, there were eighteen deaths; this gives a mortality of 15·8 per cent. Seventy-three of the total had other wounds complicating, and twenty cases came to amputation—*i.e.*, an amputation percentage of 17·9. Fifty-five of the series were associated with damage to bone, the remainder being penetrating or perforating wounds of the soft structures.

Injuries of the Ankle-Joint.

Anatomical Considerations.—The ankle-joint is a mortice or hinge joint containing one uncomplicated synovial membrane. Anteriorly and posteriorly the synovial cavity presents an uncomplicated pouch which occupies a transverse position with regard to the foot (see Fig. 175). Externally the inferior tibio-fibular joint is provided with a synovial membrane, and this bursal sac is apt to become infected in gunshot injuries involving the external aspect of the ankle-joint. In close proximity to the ankle-joint are the astragalo-scaphoid and the astragalo-calcanean joints, while in close relation to the inner aspect of the joint are the posterior tibial artery, vein, and nerve. The ankle-joint is surrounded by an arterial anastomosis.

Frequency.—Out of 2,000 consecutive cases seen at a base hospital, there were 40 cases of injury to the ankle-joint; this gives a percentage of 2.

Nature of Injury.—Wounds involving the ankle-joint almost invariably involve fracture of bone. Thus, the internal malleolus or the external malleolus may be shot away, detached, or comminuted. Again, wounds

involving the ankle-joint may similarly involve the tarsal and metatarsal joints, and may be most extensive in nature. Frequently tendons of the muscles in close relation to the inner and outer aspects of the joint are contused, torn, or completely divided.

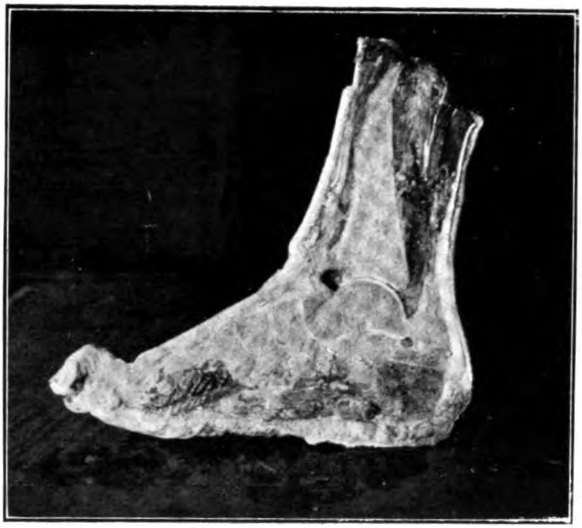


FIG. 175.—Section through an ankle-joint.
Note the pouches anteriorly and posteriorly; also the bursa beneath the tendo Achillis.

Infection.—The ankle-joint is probably less prone to infection than any other joint in the body, though when infected the same organisms are met with. *B. coli* has been a very constant organism in association with wounds of the foot and ankle-joint.

TREATMENT.

A. **On the Battlefield.**—The leg should be placed on a splint constructed in such a way as to keep the foot at a right angle. A modification of the old box splint made from two pieces of a ration box and a sandbag will answer all requirements. The wound should be dressed with a first field or shell dressing and the foot fixed at a right angle by means of a puttee. The patient may be given a quarter of a grain of morphia hypodermically, and then carried down to the advanced dressing station.

B. **At the Casualty Clearing Station.**—Unless the wound is severe, the patient, after the wound has been inspected and dressed, may be sent direct to the base. If, however, the wound be extensive, it should be excised, a Carrel-Dakin dressing applied, put up in a Robert Jones crab splint, and sent to the base.

C. **At the Base Hospital.**—Treatment will depend upon the position and nature of the wound and the degree of infection in the joint. If the

internal malleolus be damaged and the joint definitely infected, it is best to remove the malleolus subperiosteally. If, on the other hand, the external malleolus is fractured, together with the lower end of the fibula (a not uncommon occurrence), then subperiosteal resection of the lower fractured end of the fibula is the operation of choice, for then the inferior tibio-fibular articulation is exposed. When the infected joint cavity is by these means exposed, Carrel's tubes are put into the joint, one anteriorly and one posteriorly, and hourly instillation of the hypochlorite solution is carried out.

It frequently happens that wounds of the ankle-joint which have been excised at the casualty clearing station, and in which the Carrel-Dakin treatment has been started at once, do not give rise to infection of the synovial membrane. By continuing the Carrel-Dakin treatment at the base hospital, the wound into the joint, even though it involves bone, becomes shut off from the exterior by adhesions which rapidly become covered with young granulation tissue. As soon as the external wound is surgically sterile (two organisms to five fields), secondary suture is performed, and the greater number of these sutures have healed *per primam.*

Should the joint be wounded from behind and be infected, then division of the tendo Achillis gives an excellent approach to the joint cavity, and sterilisation can be effected through the posterior wound. Five such cases did excellently, for the joint and wound were sterile at the end of the tenth day, secondary suture was performed, the wounds healed *per primam*, and the patients recovered perfect movement.

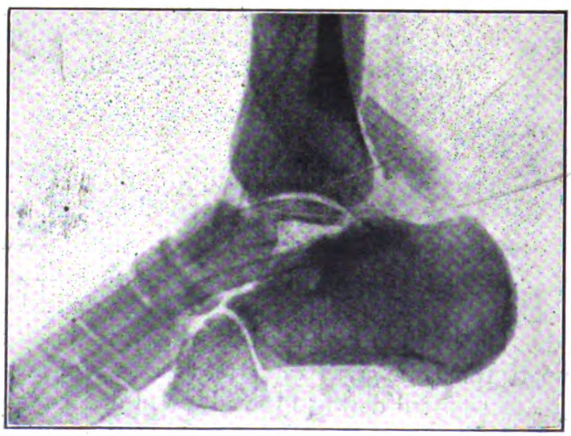


FIG. 176.—Wound of ankle-joint for which astragalectomy was performed. The X-ray shows the resulting cavity undergoing sterilisation by the Carrel-Dakin process.

Joints sterilised by subperiosteal resection of the internal or external malleoli have also done remarkably well, and the end-results of fifteen cases gave perfectly movable joints in nine, stiff joints with partial move-

ment which was improving in three, while the other three cases are still under treatment.

If, despite all efforts, the joint condition is unsatisfactory and slow of sterilisation, and this obtains when the infection is streptococcic in origin, then astragalectomy gives the best results.

Should the X-ray show fracture of the astragalus, then infection of this bone is almost certain to be present, and astragalectomy is the best practice.

Astragalectomy, then, is called for in cases of virulent infection of the joint where the joint is slow to sterilise and the cartilages are becoming involved, and also in cases of infected fracture of the astragalus.

When the astragalus has been removed, the wound is left widely open, and treated by Carrel's method until sterile, when it is sutured.

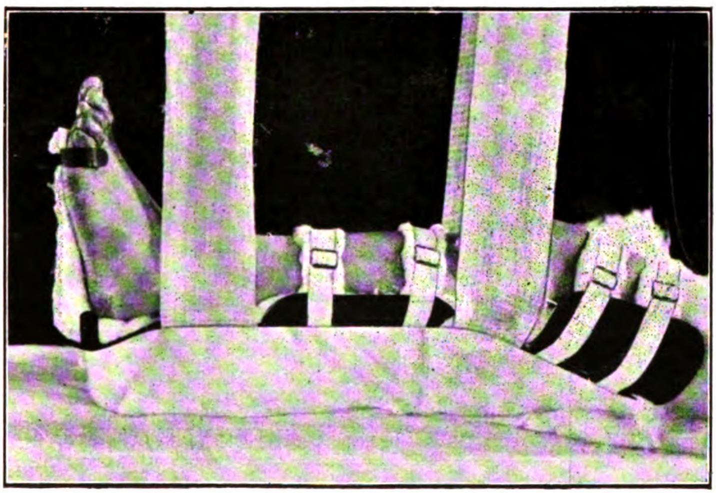


FIG. 177.—Jones's crab splint for ankle injuries applied.

During sterilisation and after suture these wounds are best nursed in a Jones's crab splint (see Fig. 177), as the foot can be always kept at a right angle and inverted.

FIG. 178.—Jones's crab splint for injuries about the ankle-joint.

Should the ankle-joint be hopelessly disorganised and form but part of an extensive wound of the foot which is highly infected, then amputation in the lower third of the leg is the only treatment.

During the period of sterilising the wound it is most important to see that the foot is kept at right angles or in slight dorsiflexion and inverted. As soon as the wounded man begins to walk or bear weight on the foot, *the sole of the boot, and also the heel, must be raised on the inner side, and he must be made to walk with his toes turned inwards.* This is a most

FIG. 179.—Extensive wound of foot involving the ankle-joint (external view).

FIG. 180.—Extensive wound of foot involving the ankle-joint (viewed from dorsal aspect).

important precaution, as neglect of this will lead to deformity and disability.

Of forty cases of gunshot injuries of the ankle-joint, all of which were caused by high explosive, three necessitated amputation (8 per cent.), twenty-eight recovered with good movable joints, and the remaining nine,

which show stiffness, are still under treatment. There was not a case of ankylosis.

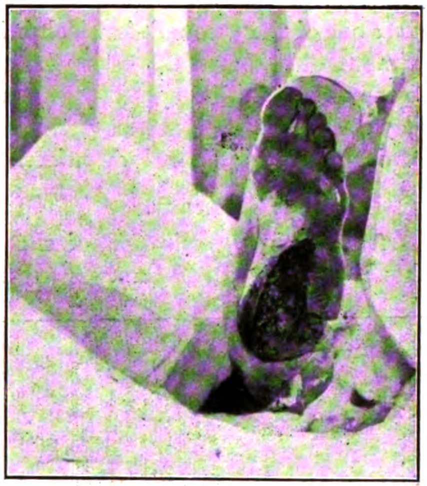


FIG. 181.—Extensive wound of foot involving the ankle-joint (viewed from the sole). This extensive wound was sterilised by the Carrel-Dakin treatment, and at the time of writing is doing well. The joint is sterile and shut off, and movements are free.

The Tarsal and Metatarsal Joints.

Wounds of the tarsal joints are amongst the most difficult of any to sterilise. The synovial membrane of the tarsal joints is a complicated

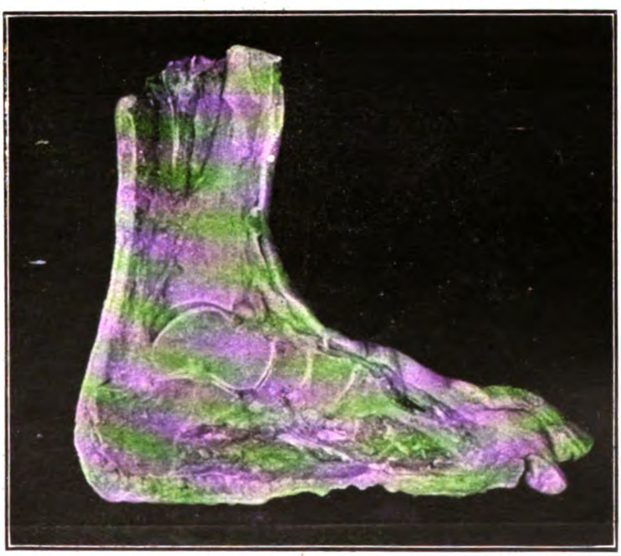


FIG. 182.—Section through tarsus to show the tarsal joints.

sac, and when once infection has established itself it is very difficult to eradicate. These wounds are most frequently associated with fracture

of the tarsal and metatarsal bones, and are but part of one extensive wound.

It is very rare to see one of these wounds in which infection is not firmly established by the time the base hospital is reached.

Like wounds of the ankle-joint, they rarely threaten life by general infection, but they lay the patient up for a considerable period, and require much attention in order to get rid of the local infection.

Treatment.

A. **On the Battlefield.**—After application of the first field or shell dressing the foot should be put up and immobilised in the same way as

FIG. 183.—Extensive wound of the tarsal and ankle joints, highly infected.

FIG. 184.

Patient on right shows wound healed two months after infliction. Part of the tarsus was resected. Note the splay condition of the foot. The eversion was quite correctible, and patient was fitted with boots raised along the inner side of the sole and heel. This same man had an infected wound of his left ankle-joint. The joint completely recovered, and he was walking well in his altered boots.

recommended for injury of the ankle-joint. Morphia (gr. ¼) may be given to relieve pain.

B. **At the Casualty Clearing Station.**—It is at this unit that early surgical treatment should be given. After thoroughly cleaning the skin, cutting and scrubbing the toe-nails, and cleaning in between the toes (turpentine cleans the feet probably better than anything else), and shaving the leg, the wound should be excised, and any fractured tarsal or metatarsal bones should be at once resected. After procuring hæmostasis, a Carrel-Dakin dressing should be applied and the patient evacuated to the base. Cases in which this early treatment has been carried out have done well, sterilised quickly, and allowed of the wound being closed. The end-results have

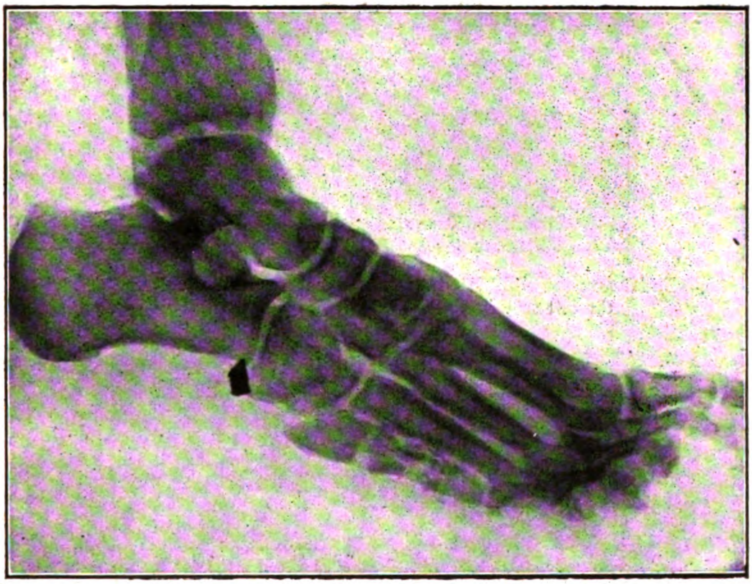


FIG. 185.—Wound of the sole of the foot involving the calcaneo-cuboid joint.

been good, and the average time before weight can be borne on the damaged foot has been seven to eight weeks. Cases in which resection of damaged bone has not been carried out have hung on indefinitely. Sinuses have formed, and from time to time sequestra have come away. It is weeks before these patients can put their damaged feet to the ground, and the end-results have been stiff, painful, and useless feet.

C. **At the Base Hospital.**—Sterilisation of the wound is carried on at the base hospital, and secondary suture is performed where practicable. The foot is nursed on a Jones's crab splint, and later, when the patient gets up on to crutches, a Sayre's apparatus is substituted. The boot should be crooked in exactly the same way as recommended for injuries of the ankle-joint before the patient starts to bear weight on the foot, and throughout

the treatment it is of the utmost importance to *keep the foot at right angles and inverted.*

FIG. 186.—Patient on the right is the same patient as shown in Fig. 183. Patient on the left sustained an injury of the left metatarsus.

If the metatarsus and tarsus are hopelessly mutilated, with tendons, nerves, and arteries divided, so that the foot is one stinking mass, then amputation through the lower third of the leg is the only remedy.

The Shoulder-Joint.

Anatomical Considerations.—The synovial cavity of the shoulder-joint is a large bursal sac with one annex, the subscapularis bursa. The cavity is traversed by the tendon of the biceps brachialis muscle, and the tendon of the subscapularis muscle is plainly seen from within the joint cavity (see Figs. 187 and 188). In close relation to the shoulder-joint are the acromio-clavicular articulation, the subacromial bursa, and the main vessels and nerves of the upper extremity. The joint is extremely lax, and as soon as air is admitted to its interior the head of the humerus tends to fall away from the glenoid cavity. This is an advantage from the point of view of sterilising the joint when infected, as it will be seen from the accompanying figures that the synovial cavity under these conditions forms a sump.

Frequency of Occurrence.—Out of 2,000 consecutive cases of wounds, there were 30 wounds of the shoulder-joint; this gives a percentage of 1·5.

Nature of Wound.—Wounds of the shoulder-joint may be penetrating or perforating, complicated or uncomplicated.

FIG. 187.—Section through shoulder-joint, showing the joint to be one large bursal sac

FIG. 188.—Section through shoulder-joint.
Note tendons of biceps and subscapularis muscles.

Penetrating wounds are the result of high explosive or shrapnel, rarely of rifle bullets. Soft parts or bone may be involved. In the case of bone the injury may range from a clean perforation of the head of the humerus to comminution of varying degree. The glenoid cavity has been very rarely involved.

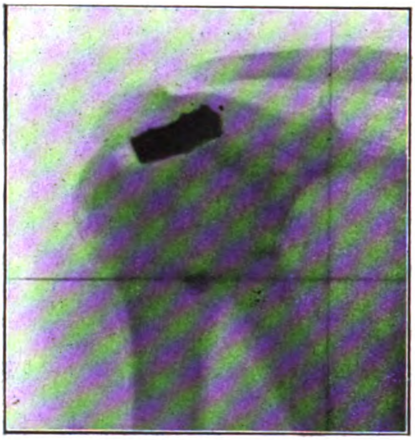


FIG. 189.—Penetrating wound of shoulder-joint.

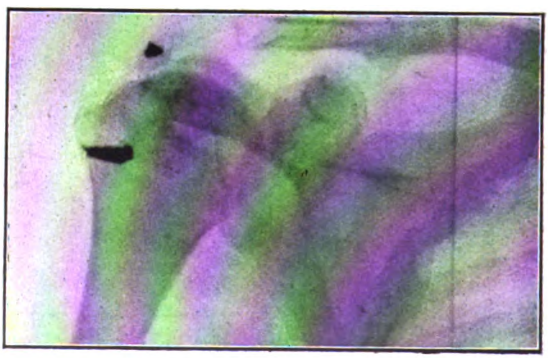


FIG. 190.—Penetrating wound of shoulder-joint with fracture of head of humerus

Perforating wounds of the shoulder-joint are interesting. Many cases are now on record, and are far from uncommon, in which the shoulder-joint has been perforated antero-posteriorly by a small missile such as a rifle bullet or small piece of grenade. The head of the humerus, which seems to show what might almost be termed an immunity to comminution, is usually cleanly perforated, and but little disability results, the patient showing good movements at the end ot three weeks. It is difficult to explain why it is that the head of the humerus is so seldom comminuted as the result of gunshot wounds, but it is a very noticeable fact, for we

have seen it repeatedly perforated by such missiles as revolver bullets, pieces of grenade, and even pieces of shell and shrapnel balls, without any comminution taking place.

Perforating wounds of the shoulder-joint from side to side are more complicated, for the missile, after perforating the joint, may not emerge from the body, but come to rest in the thoracic cavity, the root of the neck, or even the face or head.

Wounds of the shoulder-joint may be complicated by damage of the acromio-clavicular articulation, fracture of the acromion process, or fracture of the clavicle.

More extensive wounds of the shoulder may result in laying the joint widely open and the carrying away of large pieces of tissue ; thus, the acromion process, the outer end of the clavicle, and part of the head of the humerus, together with the soft structures clothing them, may be carried away completely by a large piece of shell.

In a number of instances the upper extremity has been completely torn away from the trunk through the shoulder-joint. This has occurred as the result of the burst of a Minenwürfer.

The changes seen in the joint as the result of infection differ in no respect from those seen in other joints, and the organisms of infection are the same.

Treatment.

A. **On the Battlefield.**—The joint must be immobilised by fastening the arm to the side by means of a puttee or triangular bandages and bandaging the forearm to the front of the chest. After a dressing has been applied the wounded man can walk to the advanced dressing station.

B. At the Advanced Dressing Station or Field Ambulance.—The dressing should be inspected, and also the condition of the circulation in the hand. If everything is satisfactory, the patient is sent on to the casualty clearing station ; if, on the other hand, the limb is badly mangled and there is no circulation or feeling below the lesion, amputation should be performed without delay and a Carrel-Dakin dressing applied. We are absolutely convinced that the sooner amputation is performed in the case of hopelessly mangled limbs the better, for cases we saw at a casualty clearing station during the Somme offensive in 1916, which had been so treated at the field ambulances, did far better than similar cases in which the mangled limb had been left on until the casualty clearing station was reached.

C. **At the Casualty Clearing Station.**—Small penetrating wounds of the shoulder-joint can be safely left until the base hospital is reached. The skin around the wound should be thoroughly cleaned and the axilla shaved. The arm is then bandaged to the side, and the patient at once sent to the base. Should the missile have entered the root of the neck or the chest, the shoulder wound need not be touched, as the majority of these cases,

if the wound of entry be small, run an uncomplicated course so far as the shoulder-joint is concerned. Under these conditions the treatment should rather be directed to the chest-lesion or to any damage that may have occurred in the neck, such as hæmorrhage, etc. The missile should be carefully localised with the X-ray, and if feasible it should be removed. If, however, the missile is lying in the joint cavity, it must be removed under the strictest aseptic precautions.

Small penetrating wounds of the shoulder-joint taking an antero-posterior course should be left alone. The skin around the wounds should be thoroughly cleaned and the arm bandaged to the side.

Larger wounds of the shoulder of the lacerated type involving bone should be excised and a Carrel-Dakin dressing applied. If the head of the humerus be comminuted, the question of excision arises. We are of opinion that excision of the head of the humerus, however comminuted, is wrong practice. We have witnessed the end-results of a number of these cases at a base hospital where excision of the head of the humerus for comminution had been performed at a casualty clearing station, and in every case, without exception, the results, both immediate and remote, were most unsatisfactory. Some cases contracted osteomyelitis of the humerus; others suppurated indefinitely, large sequestra coming away, leaving the patient with a flail joint; whilst others, through extensive formation of fibrous tissue, developed neuritis and trophic conditions in the limb. We never saw these complications occur when the head of the humerus, though comminuted, had been left alone. It is quite sufficient treatment to excise the wound thoroughly, leave the joint open, and into the depths of its cavity insert one Carrel's tube. A Carrel-Dakin dressing is then applied to the excised wound, and the patient is sent to the base with his arm bandaged securely to his side.

If the acromion process is badly fractured it is best to remove it, as this renders the sterilisation of the joint all the easier.

Should the damage about the shoulder-joint be irretrievable, and the circulation and sensation in the limb absent, then disarticulation should be performed and a Carrel-Dakin dressing applied to the open stump.

D. **At the Base Hospital.**—The day after arrival at the base hospital the dressing is changed and the limb is put up on a Thomas's straight arm-splint with extension. The Carrel-Dakin treatment is continued, and at the end of the fourth or fifth day the joint cavity becomes shut off from the wound by adhesions, over which grows young granulation tissue. The wound becomes sterile at the end of the tenth to the fourteenth day, when secondary suture is performed. *We have not found it necessary in a single case to excise the head of the humerus, however comminuted.* After suture of the wound the arm is still kept abducted for another fortnight or three weeks. The stitches are removed at the end of the tenth day. Between the fourth and fifth week following injury the splint is removed under an anæsthetic and the arm is brought down

FIG. 191.—Large wound of shoulder-joint six weeks after infliction.
The head of the humerus was comminuted. Result : Movements perfect at the end ot the seventh week.

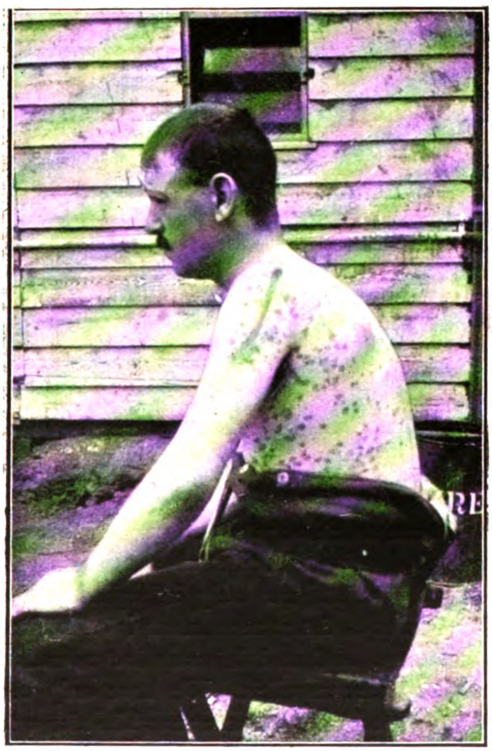


FIG. 192.—Extensive wound of shoulder-joint with comminution of the head of the humerus.
Wound sutured and healed and movements perfect at the end of the sixth week.

to the side. This necessitates the breaking of one or two friable adhesions. All movements of the shoulder-joint are performed once while the patient is under the anæsthetic, and the arm is put in abduction for another week. At the end of this time massage and passive movements are begun, and the results have been surprisingly satisfactory.

The shoulder-joint appears to be the easiest joint in the body to sterilise, probably on account of the simple nature of its synovial cavity, and this despite comminution of the head of the humerus. Wounds in this region

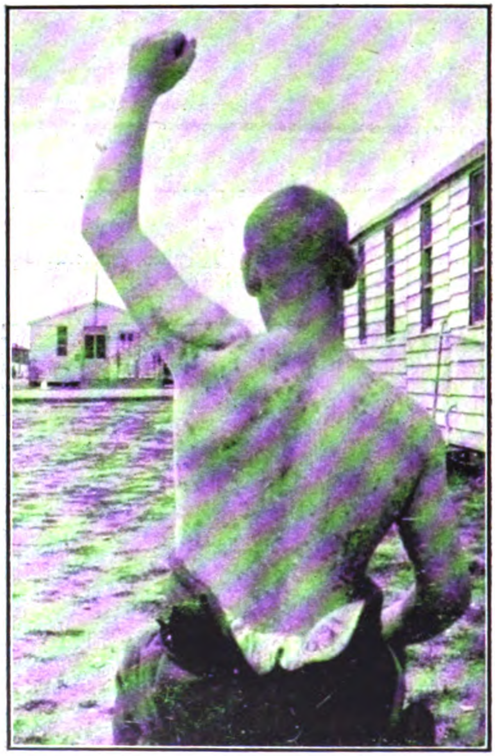


FIG. 193.—Same patient as Fig. 192 at end of sixth week.

which certainly eighteen months ago would have undergone disarticulation at the shoulder-joint have, when treated by the Carrel-Dakin system, given most astounding results, not only in rapidity of sterilisation and secondary suture, but also as far as movement is concerned.

The **Complications** to be feared in extensive wounds of the shoulder-joint are ankylosis and osteomyelitis. We have only seen osteomyelitis follow excision of the head of the humerus while the wound was septic; while ankylosis has not occurred in any of our cases. Should osteomyelitis supervene and threaten life, then amputation is the only treatment.

The Elbow-Joint.

Anatomical Considerations.—The synovial cavity of the elbow-joint is complex in variety, comprising one large bursal sac for the humero-ulnar and radio-humeral articulations and an annex for the superior radio-ulnar articulation. The humero-ulnar and radio-humeral cavity is divided into spacious anterior and posterior compartments by the articular ends

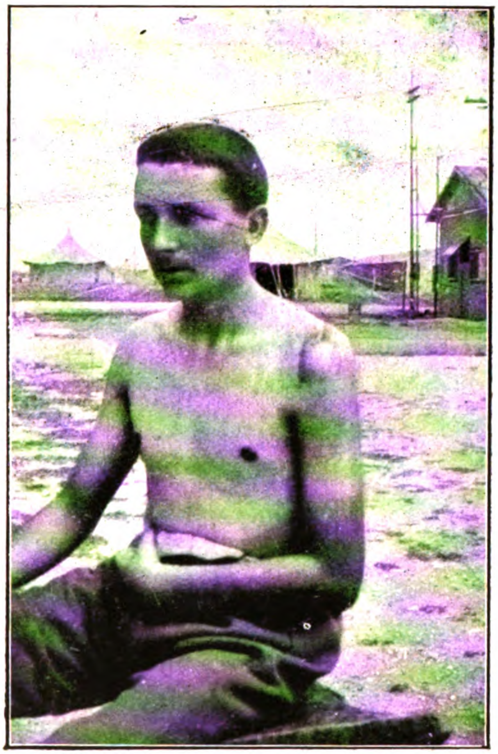


FIG. 194.—Large wound of shoulder involving head of humerus healed after suture at end of a fortnight.
Movements good at the end of a month. Part of the acromion process has been removed.

of the bones (see Figs. 196, 197). The superior radio-ulnar articulation is surrounded by the orbicular ligament, which is in close apposition to the lateral articular surface of the bone.

In close relation to the elbow-joint are the brachial artery, the ulnar and median nerves and the termination of the musculo-spiral trunk, and a rich arterial anastomosis surrounds it. Movements of flexion, extension, pronation, and supination are permitted at this joint.

Frequency of Occurrence.—From 2,000 consecutive cases of wounds there were 42 cases of injury to the elbow-joint, giving a percentage of 2·1.

Nature of Injury.—Wounds of the elbow-joint are either lacerated, penetrating, or perforating, and practically always involve fracture of bone. Any of the bones entering into the formation of the joint may be involved ; thus, one of the condyles of the humerus may be detached, the olecranon process may be fractured, the head of the radius may be comminuted, or the whole joint may be carried away.

Dislocation of the elbow-joint has not been uncommon ; it may either be simple or compound, is usually caused by the falling in of a dug-out

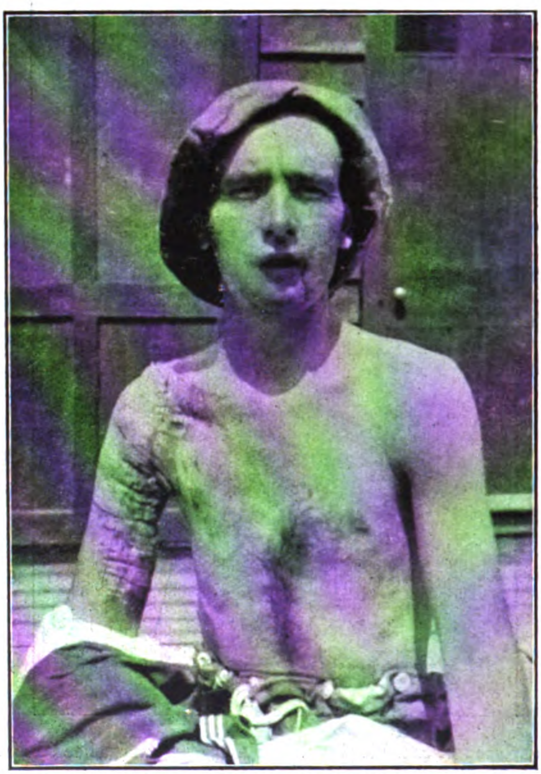


FIG. 195.—Large wound of shoulder sutured and healed at the end of a month. This patient also had a fractured mandible and a penetrating wound of the knee-joint.

or the parapet, and is usually associated with fracture of the coronoid process of the ulna.

The ulnar or median, or the terminal divisions of the musculo-spiral nerve may be contused, torn, or completely divided, giving rise to paralysis corresponding to the distribution of the injured nerve.

In a few cases the whole joint cavity with the soft structures surrounding it is so lacerated and disorganised that the whole of the forearm is one useless dead mass requiring amputation.

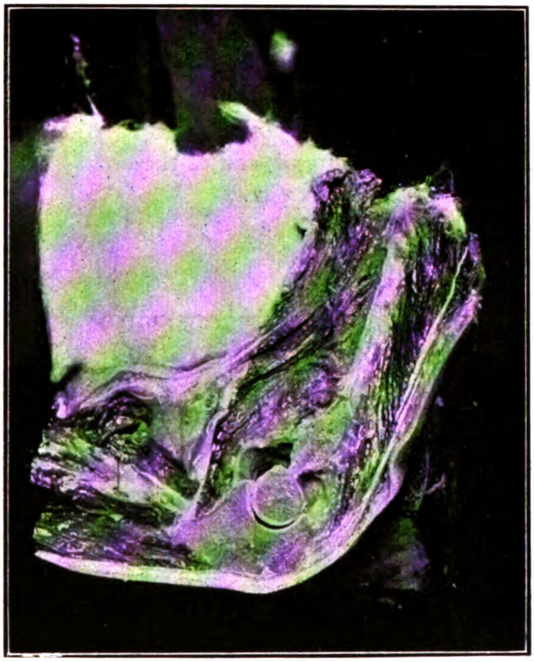


FIG. 196.—Section through elbow-joint.
Note division of synovial sac into anterior and posterior compartments by the articular ends of the bones.

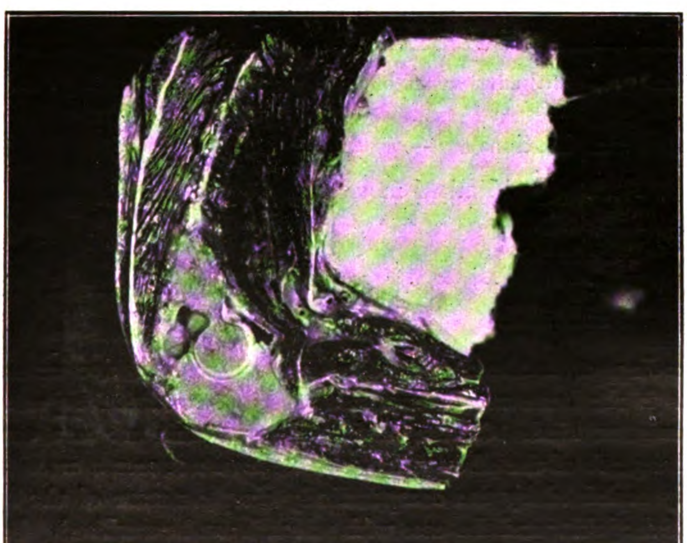


FIG. 197.—Section through elbow-joint, showing anterior and posterior division of synovial cavity.

Infection of the elbow-joint differs in no way from that of other joints, for precisely the same organisms have been isolated.

Complications.—Immediate complications are—

(1) A spreading or localised periostitis about the lower end of the humerus and the upper end of the ulna.
(2) Osteomyelitis and septicæmia.
(3) Paralyses.
(4) Hæmorrhage.

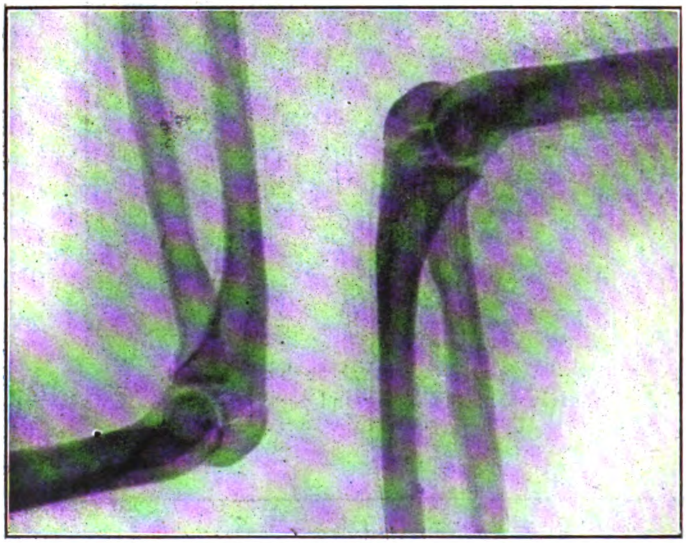


FIG. 198.—Penetrating wound of elbow-joint involving fracture of ulna.

Remote complications are—

(1) Stiffness and limited movements.
(2) Ankylosis.
(3) Deformity.
(4) Wasting of muscles and trophic phenomena in the forearm and hand.

Spreading or localised periostitis has occurred in five cases. The humerus is the bone usually involved, and the condition appears to be of a persistent kind. Osteomyelitis and septicæmia are rare complications of wounds of the elbow-joint, and we have not seen a case. This is probably explained by the comparatively simple nature of the synovial cavity of the joint; and the ease with which it can be sterilised. Paralyses have not been infrequent, and have been chiefly confined to the ulnar nerve and the divisions of the musculo-spiral. Hæmorrhage has been a rare event since the adoption of the Carrel-Dakin process.

Stiffness and limited movements are very apt to follow injuries of the elbow-joint. Limitation of flexion and extension, and of the movements of the superior radio-ulnar articulation, especially inability to supinate the forearm fully, are the common sequelæ. This may be due to either intra-articular or extra-articular causes, or both. If a wound has been open and granulating for some length of time, much fibrous tissue is formed around the joint, which will seriously limit movement. Again, if a fracture of the lower end of the humerus or the coronoid process of the ulna has occurred, then flexion may be impossible above a certain point. Ankylosis and deformity may occur owing to the joint having been fixed in a faulty position ; this is, unfortunately, not a rare event. Wasting of muscles and trophic phenomena will follow when the large nerves of the forearm have been torn or completely divided.

Treatment.

A. **On the Battlefield.**—The arm, after a dressing has been applied, should be put up on an internal angular splint if this is available. Two pieces of a ration box will usually serve the purpose well, and the patient should be sent directly to the casualty clearing station. These patients can usually walk ; hence there should be no delay in getting them out of the line.

B. **At the Field Ambulance.**—Nothing further need be done at this unit unless the limb below the injury is dead and useless. If this be the case, immediate amputation should be performed before infection has time to spread. This procedure will also limit the shock occasioned by transport.

C. **At the Casualty Clearing Station.**—An X-ray should be taken to ascertain the nature of the damage done and to show the presence and position of foreign bodies. This done, the patient should be anæsthetised, the whole limb thoroughly cleaned, and the axilla shaved. Further treatment will depend upon the position of the wound. If the wound be on the posterior aspect of the joint and involve fracture of the olecranon process (a not uncommon event), the wound should be carefully excised and sutured. The joint is now opened by an incision on its outer aspect, if the surgeon is satisfied that it is infected, the anterior and posterior sacs of the synovial cavity are opened, and one Carrel tube laid into each.

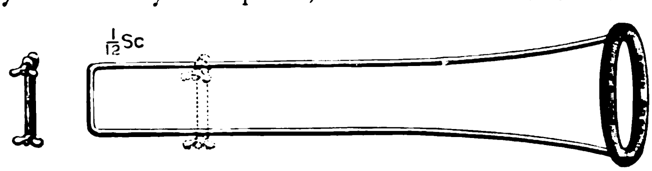


Fig. 199.—Thomas's straight arm-splint.

The orbicular ligament is next divided, and a third Carrel tube is inserted down to the superior radio-ulnar articulation. A dressing is now applied, and the limb is put up on a Thomas's straight arm-splint with extension.

Should the wound be over the inner aspect of the joint, it should be excised, and if feasible it should be sutured; the joint is opened from its outer aspect, and the rest of the treatment is as described above.

If the wound is on the outer aspect of the joint, it should, after excision, be dealt with in the manner already recommended, the newly excised wound being left widely open. By this treatment every part of the synovial cavity is open, and readily permits of sterilisation. It is impossible to sterilise an elbow-joint through a posterior incision alone, as only the posterior sac of the synovial cavity is accessible; the whole joint must be sterilised, otherwise failure is bound to follow. The only possible approach

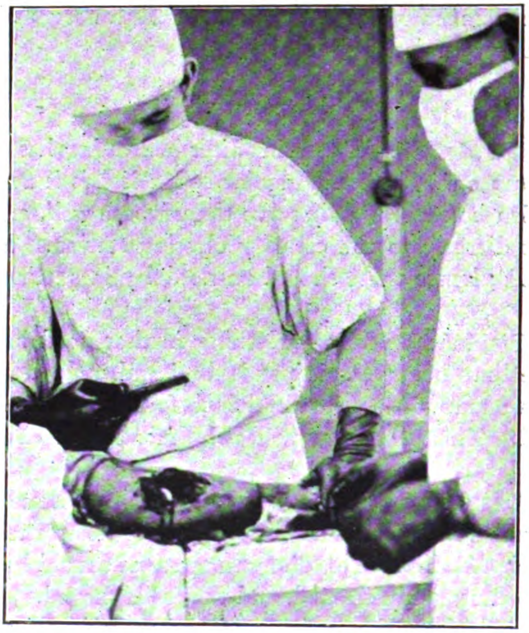


FIG. 200.—Excision of wound on outer side of the elbow-joint prior to applying Carrel's tubes.

to the whole of the synovial cavity is by means of an incision on its outer aspect. Extension keeps the articular surfaces of the bones apart, and by these means sterilisation has proved both efficient and rapid.

D. **At the Base Hospital.**—The dressing is changed on the day following arrival, and the extension tightened up if necessary. Sterilisation is carried on, and at the end of a week the joint cavity is shut off. At the end of ten or twelve days the wound is usually sterile, and secondary suture is performed. The stitches are removed at the end of the tenth day, and the forearm is put up in flexion to a right angle and in full supination. Should wrist-drop be present, the hand is put on a dorsiflexion splint. At the end of another week or ten days, after the wound is soundly healed,

the patient is given an anæsthetic, preferably gas, and the elbow-joint is moved once to its full extent in every direction ; thus, extension, flexion, pronation, and supination are all performed once, and the joint is finally left and secured in full flexion with the forearm fully supinated, which position is maintained for a fortnight. If wrist-drop is present, the dorsi-

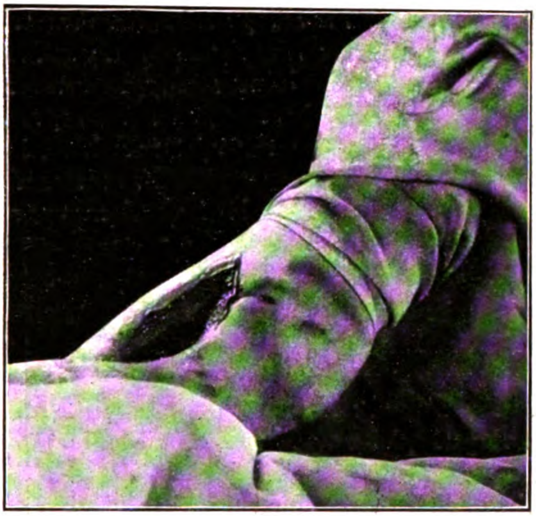


FIG. 201.—Wound of elbow-joint sterile and ready for secondary suture. The joint cavity is completely shut off. Twelve days after injury.

flexion splint is still kept on. At the end of a fortnight massage is commenced, and the patient is encouraged to use his arm, and if wrist-drop does not complicate the injury he is allowed to carry small weights. At this stage the patient is sent to an orthopædic depot, where further massage and exercises are carried out.

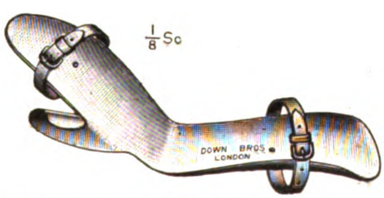


FIG. 202.—Dorsiflexion splint for hand.

We have never practised excision of the joint soon after injury, for we have never seen any reason to resort to this treatment. We have been concerned in the after-treatment of several cases in which excision of the joint had been performed soon after injury at the casualty clearing station, and all cases but one were disappointing.

FIG. 203.—Gunshot injury of elbow-joint.

The joint is shut off and sterile. This patient is wearing a dorsiflexion splint for wrist-drop.

FIG. 204.—Same wound as Fig. 203 after suture, seventeen days after injury.

We have, since adopting the practice recommended above, never seen a case of ankylosis result. Should such a complication be inevitable, the joint must be fixed in a position just over a right angle, with the forearm slightly more supinated than pronated. We are confident that the whole secret of success lies in an early sterilisation and closure of the wound, with the minimum amount of scar-tissue formation.

The treatment of paralyses, deformity, ankylosis, etc., belongs to the domain of the orthopædic surgeon, but we would repeat that if early sterilisation of these wounds were carried out in every case there would be considerably less for the orthopædic surgeon to do. While in hospital

FIG. 205.—Two cases of injury to elbow-joint, five weeks after injury.

These patients are undergoing massage and carrying weights prior to going to orthopædic depot.

a paralysed limb must be massaged, and a dropped wrist must be kept, without intermission, in the dorsiflexed position by means of a splint, the patient wearing a sling.

If nerves around the elbow-joint are completely divided, they should be sutured at the first operation.

End-Results.—Out of forty-two cases of wounds of the elbow-joint seen from start to finish, thirty-four recovered with good movable joints. At the end of eight weeks flexion was good and extension, though not complete, was improving. These men were all able to perform useful work. Of the remaining eight cases, three had undergone excision of the elbow-joint at the casualty clearing station, and these cases did badly.

Of the remaining five, one case required amputation for secondary hæmorrhage, while the remaining four cases are still in hospital undergoing the routine treatment, two of them presenting considerable stiffness and limitation of movement.

To sum up, the essentials in treatment are—

(1) Excise the original wound as early as possible.
(2) Open the joint cavity by an incision on its external aspect if infection is present, divide the orbicular ligament, and insert three Carrel's tubes.
(3) Put up the limb in extension.
(4) Suture when sterile.
(5) Remove the stitches on the tenth day after suture.
(6) A week later put the arm in full flexion, after performing every movement once.
(7) At the end of another fortnight start massage, passive movements, and exercises.
(8) Should wrist-drop be present, keep the hand uninterruptedly in dorsiflexion by means of a splint.
(9) Massage and electrical treatment for paralysed muscles.
(10) Suture nerves if divided at the first operation.
(11) Don't excise the elbow-joint while the wound is septic.

Carpal and Metacarpal Joints.

The carpal and metacarpal joints possess a complex synovial cavity. The wrist-joint or the joint between the lower end of the radius and the first row of carpal bones is a simple diarthrodial joint, and in immediate relation, though not always communicating, is the inferior radio-ulnar articulation, this articulation being separated from the wrist-joint proper by a triangular fibro-cartilage. The carpal joints are formed between the eight carpal bones, and possess a complex synovial cavity.

In immediate relation to these joints are the radial and ulnar arteries, the ulnar and median nerves, and numerous muscle tendons.

Wounds involving the wrist may be penetrating or perforating, and practically always involve bone. Thus, the lower end of the radius or ulna may be fractured, the carpus itself may be fractured, and even some of the metacarpal bones. Perforating wounds of the carpal joints, the result of rifle bullets, have not been infrequent, and often heal by themselves. Fracture of the scaphoid bone has also been fairly common in connection with wounds in this neighbourhood. Larger lacerated wounds about the wrist may involve nerves, arteries, and tendons, together with bone, and injury to the deep palmar arch often gives rise to most troublesome hæmorrhage.

Larger wounds of the carpus, though highly infected, are much less difficult to sterilise than corresponding wounds of the tarsus.

Twenty cases of wrist-joint injury occurred amongst a series of 2,000 wounds, giving a percentage of 1.

Treatment.

A. **On the Battlefield.**—The field or shell dressing should be applied and the forearm put up on a straight splint made from a piece of ration box,

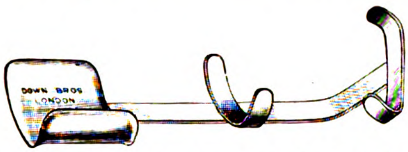


Fig. 206.—Jones's wrist-splint, for gunshot wounds through the wrist, supporting the hand in the dorsiflexed position.

with a pad under the hand to dorsiflex the wrist. The arm is put in a sling, and the wounded man can walk to the advanced dressing station.

B. **At the Field Ambulance.**—Nothing further need be done here unless the hand and wrist are irretrievably mangled, when immediate

Fig. 207.—Patient on left shows a severe wound of the left carpus and metacarpus. Wound is sterile, but too extensive for secondary suture.

amputation is called for. The patient should be sent on with as little delay as possible to the casualty clearing station.

C. **At the Casualty Clearing Station.**—An X-ray should be taken to ascertain the damage done to bone and to localise any foreign body. The hand should be thoroughly cleaned while the patient is under an anæsthetic, and the finger-nails cut short and scrubbed (turpentine will be found useful in this connection). The wound should be excised, and any detached pieces of bone removed. All bleeding-points should be ligatured, a Carrel-Dakin dressing applied, and the wrist put up on a dorsiflexion splint. Any nerves that are divided should be sutured, but divided tendons should be left until the wound is sterile. Any foreign body should be removed.

D. **At the Base Hospital.**—Sterilisation of the wound is carried on until a satisfactory bacteriological report is obtained, when secondary suture, if possible, is carried out. The wrist is kept in dorsiflexion throughout. If secondary suture is not possible, the wound edges are approximated by strapping to diminish the wound surface, and skin-grafting is carried out later. After the wound is soundly healed, the patient is sent to an orthopædic depot, where massage and finger exercises are provided. Tendon or nerve transplantation can, if necessary, be carried out at a later date.

Trophic changes in the skin as a result of divided or damaged nerves must be watched for, and the hand must be kept warm by the use of a woollen glove.

CHAPTER XVIII

GUNSHOT INJURIES OF BONE

Bone injury resulting from gunshot wounds may range from contusion to simple or compound fracture, either of a limited or extensive degree.

Simple fracture in this connection is comparatively rare, but compound fractures form a very large proportion of the wounds of the present war.

Simple fractures result either from blows with spent pieces of shell, or from the falling in of dug-outs or pieces of the parapet. They differ from the simple fractures of civilian practice in that displacement of the fragments is greater, and contusion of the soft parts is more marked.

Compound fractures differ in many details from those observed in civilian practice, in that comminution and splintering of bone are often extreme, there may be considerable loss in bony continuity, large arteries and nerves may be implicated, and there is usually severe laceration of the muscles and other soft structures.

The types of compound fracture most commonly seen are—

(1) A gutter fracture of bone without destruction of continuity. Such a fracture is usually the result of a glancing blow, and the bone may or may not be fissured.
(2) A clean perforation of bone without destruction of continuity, but practically always associated with fissure.
(3) A fissured fracture of bone with little displacement.
(4) Comminution of bone with or without destruction of continuity.

The degree of damage sustained by a bone will depend upon the nature and velocity of the missile and the angle at which the bone is struck. If the bone be struck tangentially by a missile fired at close range, the blow will probably be glancing in nature, and little damage to bone will result, the missile passing on and emerging from the tissues. If, on the other hand, the blow be direct and the velocity high, then severe comminution and splintering of the bone will follow. A rifle bullet fired at close range and striking a bone tangentially may be turned in its course, and though the wound of entry may be small, the wound of exit is large and lacerated. Again, a rifle bullet fired at close range may strike the shaft of a long bone direct, causing severe comminution, and, continuing its course, emerge from the tissues leaving a small wound of exit. This class of wound

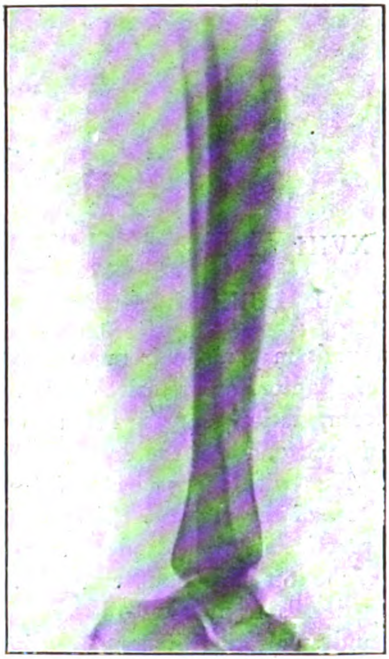


FIG. 208.—Gutter fracture of lower end of tibia (side view).

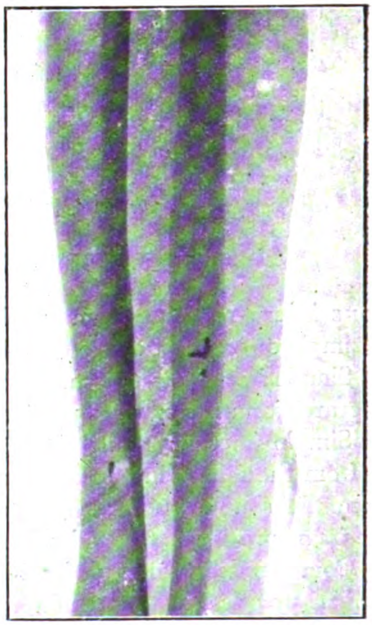


FIG. 209.—Perforation of lower end of tibia with fissure of the bone, but no destruction of continuity.

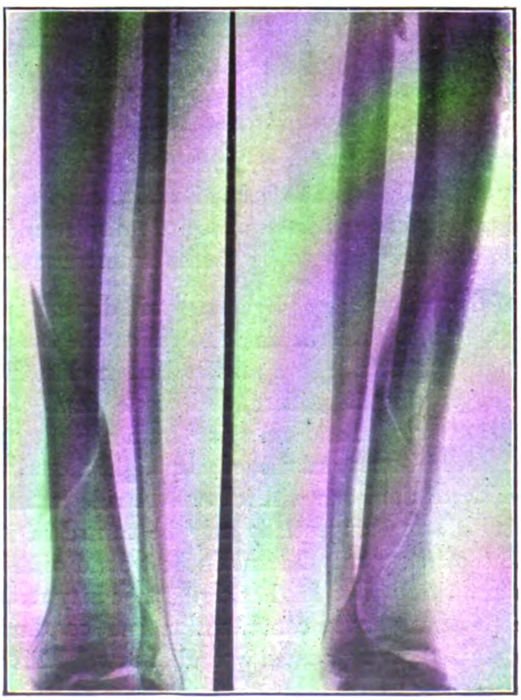


FIG. 210.—Fissured fracture of tibia with little displacement.

shows little tendency to become infected if the fracture is early immobilised. The most serious fractures are those caused by pieces of high-explosive shell or bomb. The bone is comminuted, splintered, and in some cases pulverised. Small spicules of bone are scattered broadcast into the surrounding muscles, and on more than one occasion a bony spicule has been the cause of a secondary hæmorrhage by eroding its way into a large vessel. The fractured ends of the bones are often displaced, and may be pressing upon the main vessels of the limb. Laceration of the soft structures is usually so extreme that they are scarcely recognisable, and important

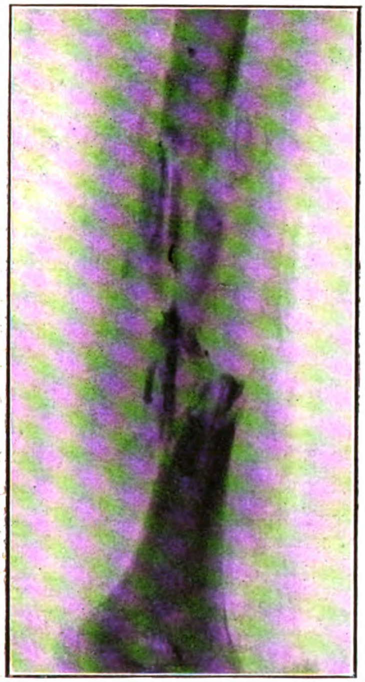


FIG. 211.—Comminuted fracture of the humerus with destruction of continuity.

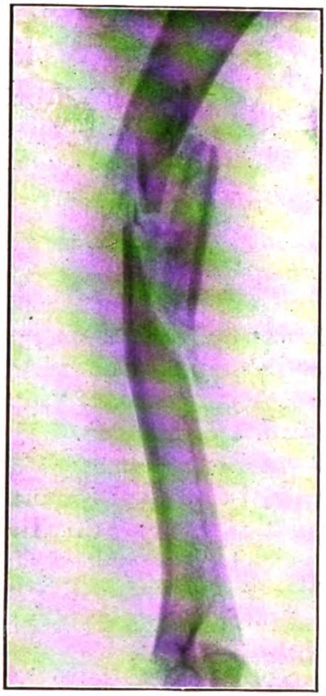


FIG. 212.—Compound comminuted fracture of the humerus the result of a rifle bullet fired at close range.
The wounds of entry and exit were small.

vessels and nerves may be displaced some distance from their normal position.

Again, fracture of bone may involve a joint cavity, either directly or indirectly. Thus, the fracture may itself be part of an injury which involves the joint directly, or a long fissure may run from the site of fracture through the articular end of the bone.

Practically all wounds involving compound fracture of bone and caused by high explosive are highly infected, and they are to-day the most difficult class of wound to deal with, for there is not only the bony injury to

consider, but also the extensive destruction and infection of the soft parts.

It is also very important to remember that bone as the result of injury has its vitality lowered just as much as, if not more than, the soft structures, and that it is therefore just as prone to infection. Bone, when once infected, is the most difficult tissue of all to sterilise.

Complications.—Immediate complications are—

(1) Osteomyelitis.
(2) Secondary hæmorrhage.

Remote complications are—

(1) Stiffness and limited movement.
(2) Deformity.
(3) Paralyses.
(4) Non-union.
(5) Sinus.

Osteomyelitis was at one time a frequent sequel of compound fracture of bone. To-day, since the adoption of wound excision, perfect immobilisation, and the process of continuous sterilisation, it is rarely seen.

Secondary Hæmorrhage may be either mechanical or septic in origin. It results either from an imperfect reduction of the fractured ends of the bone or from a detached bony spicule eroding its way into an artery, or it may be due to infection.

Stiffness and Limited Movement are probably the most common sequelæ of compound fracture. They are brought about by prolonged suppuration in wounds that have been allowed to remain open indefinitely, and in which as a result extensive fibrosis has taken place in the muscles of the wounded limb, with matting of nerves and other soft structures in fibrous tissue. Excessive and irregular formation of callus, due to growth of bone from detached spicules which have been driven into the muscles, adds to the infirmity.

Deformity results from union of the fragments in malposition.

Paralyses occur either from laceration or tearing of a nerve, or later result from the nerves being caught up in callus or scar tissue.

Non-Union may be brought about by prolonged suppuration and a consequent lowered vitality of the patient, by wide separation of the fractured ends of the bones the result of imperfect reduction and fixation of the fracture, or by the inclusion of soft tissues between the fractured ends.

Sinus.—The presence of a sinus denotes either bony sequestration or a foreign body.

Success in the treatment of compound fracture lies in early sterilisation of the wound and secondary suture. By these means excessive formation of fibrous tissue is avoided; massage and movements can

be commenced at an early date; the patient can early be got on to crutches, which avoids prolonged confinement to bed, with the consequent body-wasting and other evils; stiffness and limitation of movement are reduced to a minimum; union of the fractured bone is hastened; and as a result a number of cases can be returned to duty without leaving the country.

The Innominate Bone.

Fracture of the innominate bone may be associated with wounds of the buttock, the upper thigh, perineum, and penetrating wounds of the abdominal cavity. Large wounds of the buttock, complicated by fracture

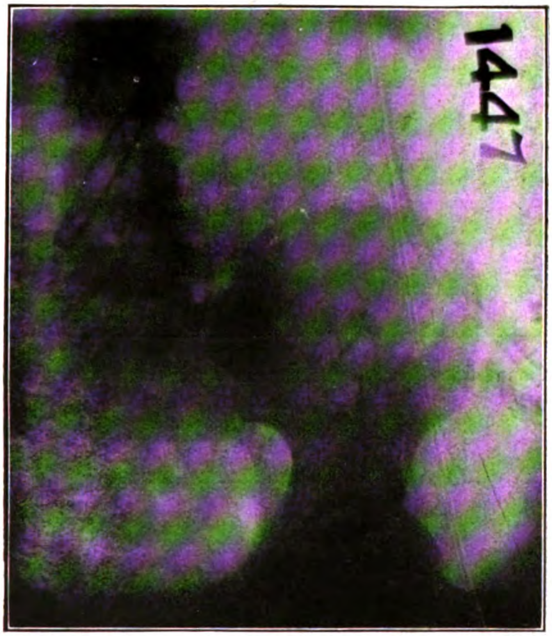


FIG. 213.—Compound fracture of the ileum.
This case was complicated by secondary hæmorrhage from the ilio-lumbar artery.

of the os innominatum, at one time formed one of the most serious and fatal types of wound with which the surgeon had to deal. They are exceedingly prone to gas-gangrene infection, and are associated with considerable shock.

Wounds in the region of the perineum which are complicated by fracture of the pubic or ischial bones are apt to involve the external genitalia, the bladder, rectum, and urethra.

Penetrating wounds of the abdominal cavity associated with fracture of the os innominatum are serious from the point of view of spicules of bone that are carried on by the missile and inflict severe damage on the viscera.

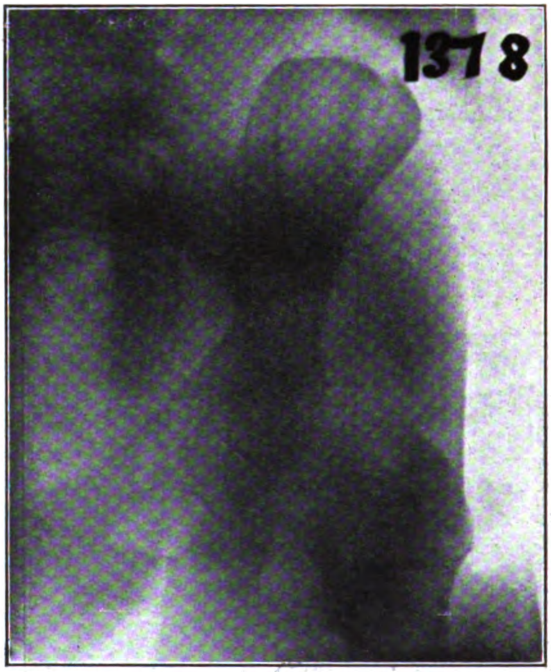


FIG. 214.—Compound fracture of the ileum associated with a wound of the buttock.

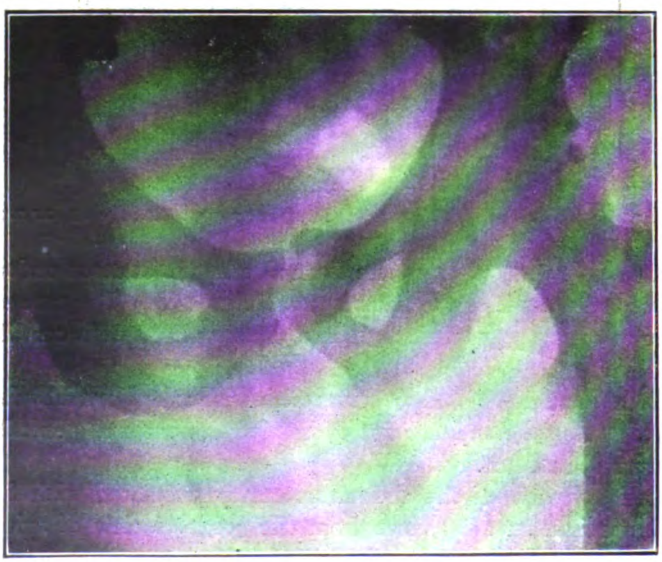


FIG. 215.—Compound fracture of the pubic bone caused by a shrapnel ball.

Complications are—

(1) Infection of both soft parts and bone.
(2) Damage to the external genitalia.
(3) Damage to the bladder, rectum, or other abdominal viscera

Owing to the proximity of the wound to the external organs of excretion, infection of a virulent type is almost universal. Gas-gangrene infec-

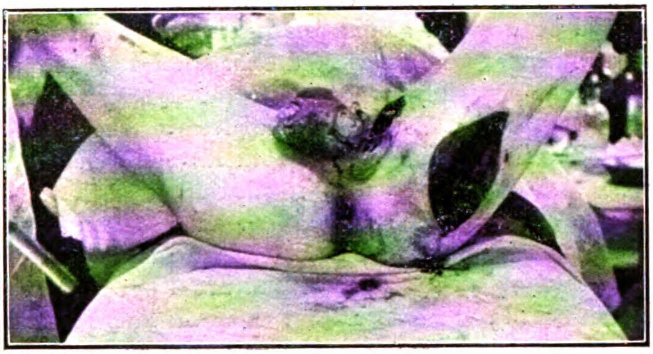


FIG. 216.—Wound of external genitalia complicated by fracture of the pubic bone.

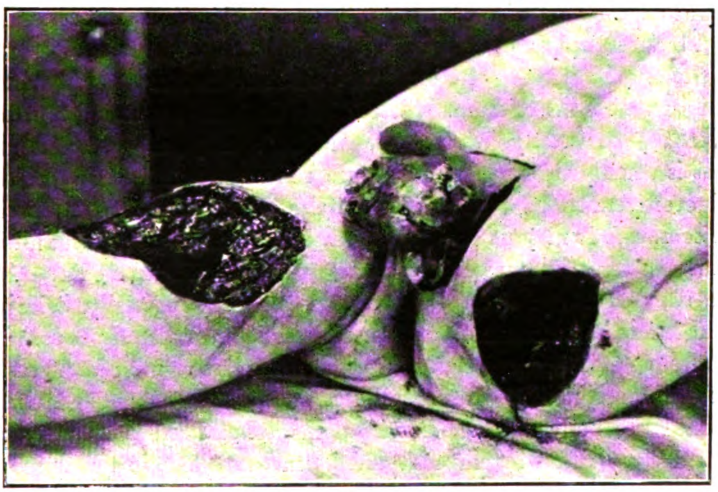


FIG. 217.—Herniation, evisceration, and gangrene of both testicles and two extensive wounds of the thighs.

Double orchidectomy performed and thigh wounds sutured after sterilisation. Patient made a good recovery.

tion of large buttock wounds was at one time as fatal a condition as any, while osteomyelitis of the innominate bone was by no means infrequent.

Damage to the external genitalia may vary from evisceration of one or both testicles to destruction of the greater part of the organs. Portions

of the penis may be carried away or partially detached, or the scrotum may be penetrated or perforated without damage to the testes. Should the wound be situated in the perineum, the urethra may be divided or the bladder penetrated. Wounds of the buttock or perineum may involve the terminal part of the rectum or the anal canal.

Treatment.

A. **On the Battlefield.**—After dressing the wound, a binder made from puttees should be wrapped around the pelvis and the patient carefully carried on a stretcher to the advanced dressing station, and from this unit he should be sent as rapidly as possible to the casualty clearing station. A quarter of a grain of morphia should be given to relieve pain. Before leaving the advanced dressing station both his legs should be fastened together and a Liston's splint applied to one side.

B. **At the Casualty Clearing Station.**—An anæsthetic should be administered, and after shaving the pubes, perineum, and anus, the skin should be thoroughly disinfected. If abdominal or pelvic viscera are involved, treatment must be carried out along the lines recommended in the chapter dealing with abdominal injuries.

Treatment of the Wound.—If the wound be situated in the buttock, it should be completely excised and a Carrel-Dakin dressing applied. All loose and dead pieces of bone should be removed and absolute hæmostasis secured before applying the dressing.

If the wound involve the external genitalia, treatment will vary with the amount of damage done. Should one or both testicles be prolapsed and partially or wholly eviscerated, and be grossly infected and gangrenous, as is usually the case under these conditions, then single or double orchidectomy must be performed. If the testicle is only prolapsed and not eviscerated, it may be replaced, and after excision of the wound in the scrotum one or two sutures may be inserted, a Carrel's tube being included in the scrotal cavity. Should the testis be only partially eviscerated, then the infected eviscerated portion should be removed and the remainder, if healthy, should be replaced. The scrotum can now be sutured and a Carrel's tube included in the scrotal sac.

Should the body of the penis be damaged and the continuity of the urethra destroyed, an attempt should be made to suture the defect after excision of the wound if the surgeon is satisfied that the vitality of the distal part of the organ warrants such a procedure. If the portion of the organ distal to the wound is dead, then it should be removed, and the proximal opening of the urethra should be sutured to the skin.

If the wound is situated in the perineum, a catheter should first be passed to ascertain whether or not the urethra is intact. The wound should then be excised. If the urethra is torn, but its continuity not entirely destroyed, it is best to leave it and trust temporarily to a urinary fistula. A Carrel-Dakin dressing should be applied to the excised wound.

Should the lower part of the rectum be wounded in association with a compound fracture of the innominate bone, then left inguinal colostomy is the operation ot choice, in order to divert the fæcal current and bring about sterilisation of the wound. After colostomy has been performed, the wound should be completely excised and a Carrel-Dakin dressing applied. The lower limb of the gut can be washed through six-hourly with half or three-quarter strength eusol. We have employed full-strength eusol and seen no harm whatever result from its use.

It is very important in the excision of these wounds to remove all loose pieces of bone, and also any portion of doubtful vitality.

During the operation 2 pints of saline solution with sodium bicarbonate and brandy should be administered subcutaneously.

As soon as the patient is fit to travel he should be evacuated to the base.

C. **At the Base Hospital.**—The wounds are dressed on the day after arrival, and bacteriologically reported upon. An X-ray is also taken to show the extent of bony damage. As soon as the wounds are sterile they are submitted to secondary suture.

Large wounds of the buttock have given most gratifying results, and out of a series of forty cases, thirty-four healed by primary union after secondary suture performed at the end of the twelfth day, twelve of these being associated with fracture of the iliac bone. Of the remaining six cases, two completely gaped and four partially; they all eventually healed, and there were no deaths.

Wounds about the perineum heal best by granulation, and have not been submitted to secondary suture.

Cases in which colostomy has been performed are treated until the wound involving the lower rectum has healed, when a Dupuytren's clamp is applied and the fæcal current again established. This done, an ordinary plastic operation is undertaken to close the colostomy wound. This operation was undertaken in three cases, all of which did extremely well. The patients have been allowed up on crutches at intervals varying from a month to six weeks from the time of receiving their injury.

The Femur.

Compound fracture of the femur at one time formed the most fatal wound of the war. Ot a series of thirty cases seen in the firing-line in 1915, eighteen died and four underwent amputation in the trenches, owing to extreme mutilation and the impossibility ot immediate evacuation. The four cases recovered. Thus, out of the remaining twenty-six cases there were eighteen deaths, giving the appalling death-rate of 70 per cent.

The femur may be fractured in any part of its length, and the fracture may involve either the hip-joint or knee-joint.

There is no classical displacement of the fragments, for they may occupy

any position, while small spicules of bone may be completely detached and distributed far and wide into the surrounding tissues.

Compound fracture of the femur may be complicated by rupture of large arteries and nerves, and excessive disruption and infection of the soft parts is nearly always present.

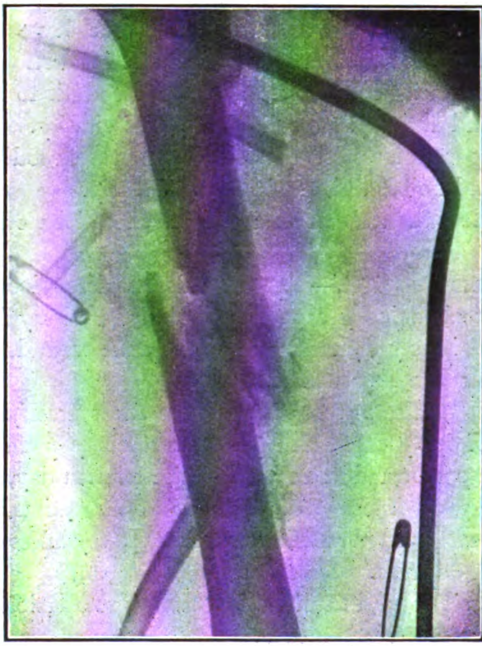


Fig. 218.—Compound fracture of femur undergoing sterilisation.

Complications most to be feared are osteomyelitis, septicæmia, embolism, and secondary hæmorrhage.

Associated with compound fracture of the femur may be foot-drop, owing to damage of the external popliteal nerve; this should always be suspected, and if present, steps should be taken from the commencement for its correction.

Treatment.

A. **On the Battlefield.**—After application of a field or shell dressing, the limb should be thoroughly immobilised *in the position in which it is found.* There should be *no attempt at reduction.* This can be accomplished by means of two rifles used as an outer splint and by pieces of ration box used as posterior, interior, and anterior splints, and secured to the limb with puttees or three-corner bandages. The damaged limb is now secured to its fellow, and after the administration of a quarter of a grain of morphia hypodermically, the patient is removed with all speed to the advanced dressing station, and thence, with as little delay as possible, to the casualty

clearing station. If the limb is hopelessly mangled and attached to the body by a few damaged structures only, it should be severed forthwith, and the main vessels tied.

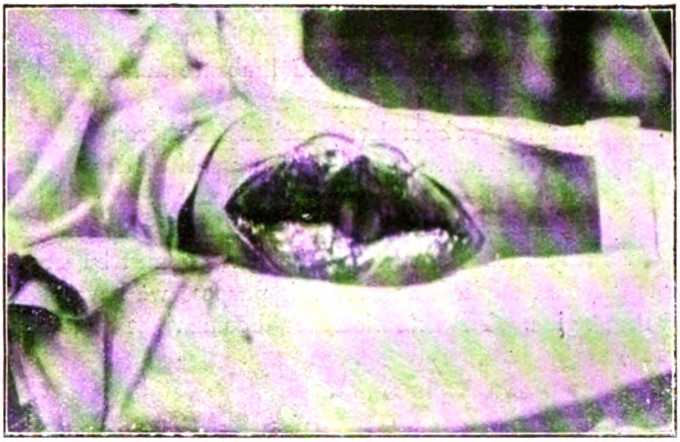


FIG. 219.—Wound of thigh with severe compound fracture of the femur excised and stitched widely open prior to applying extension and fixing on the dressing. Note tubes in depths of wound further propping it open.

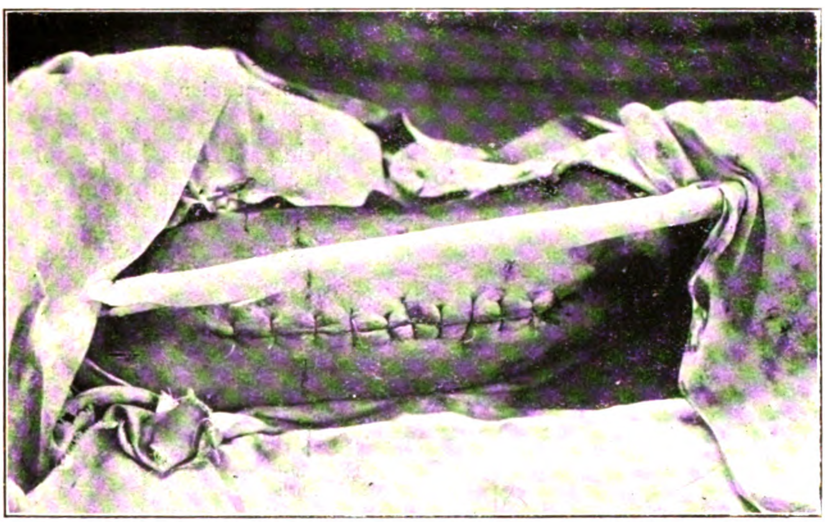


FIG. 220.—Same wound ten days later, after secondary suture. Wound healed *per primam*, and patient was up on crutches at the end of five weeks.

B. **At the Casualty Clearing Station.**—Compound fracture of the femur is always associated with severe reflex shock, and severe hæmorrhage may have occurred in the line or during transit. The patient should be

put to bed, made warm, and 2 pints of saline with brandy and sodium bicarbonate should be administered subcutaneously.

When the pulse and general condition have improved, he is taken to the operating-theatre, where an anæsthetic, preferably open ether, is administered. Another pint of saline should be slowly administered subcutaneously during the operation. When the patient is anæsthetised, the splint is removed, the pubes, perineum, anus and limb are shaved, and the skin of the whole limb thoroughly cleaned.

The wound must now be completely excised and thoroughly opened up. All obviously dead and detached pieces of bone, especially detached spicules, should be removed, and also the missile. This done, the wound is stitched widely open (see Fig. 219), and propped further open, if necessary, by means of stout rubber tubes. Absolute hæmostasis must be secured.

Extension is next applied, and for this purpose we have used sterile gauze and Page's glue. The extension should come right up to the wound (see Fig. 221).

Fig. 221.—Gauze fixed to leg by glue, for extension.

The splint is now applied, the best splint being a Thomas's knee-splint or a Wallace-Maybury extension splint. We have usually employed the latter (see Fig. 223). Should the wound involve the perineum or buttock, and so render a Thomas's knee-splint impracticable, then the

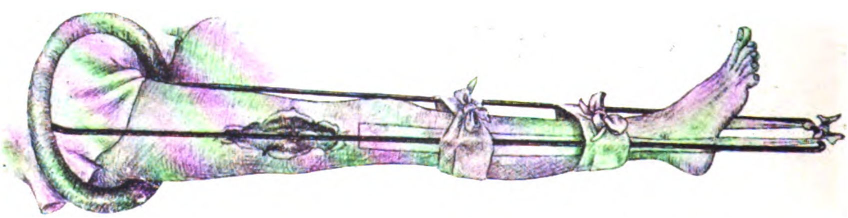
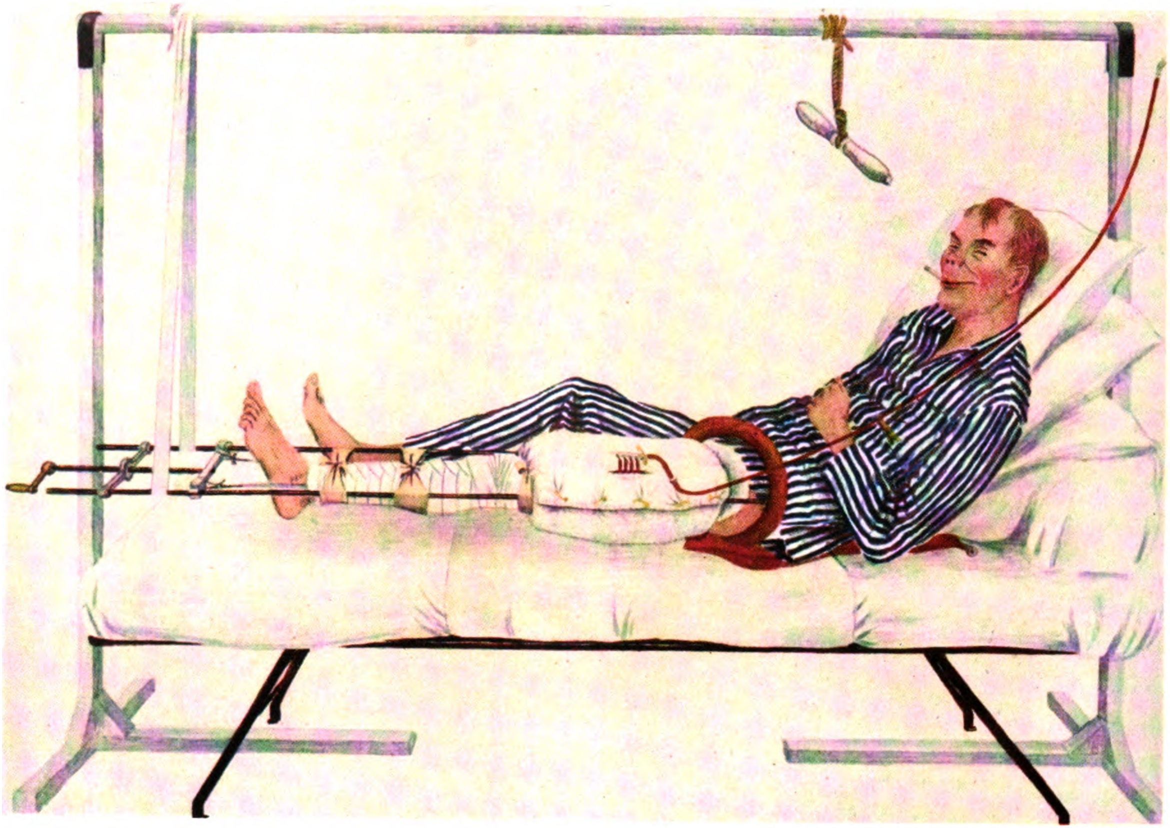


Fig. 222.—Thomas's knee-splint in position.

splint shown in Fig. 225 can be used. Fig. 226 shows the splint applied, with a back-splint extending from the upper to the lower transverse bars; extension is taken between the axilla and the stirrup at the foot of the splint.

PLATE VI.



Compound fracture of the femur. Wallace Maybury extension splint applied.
Wound undergoing sterilisation.

To face page 418.

After applying the splint, extension is now made, by means of the screw adjustment, where such is fitted, and while this is going on the surgeon manipulates the fractured ends of the bones into position, taking care

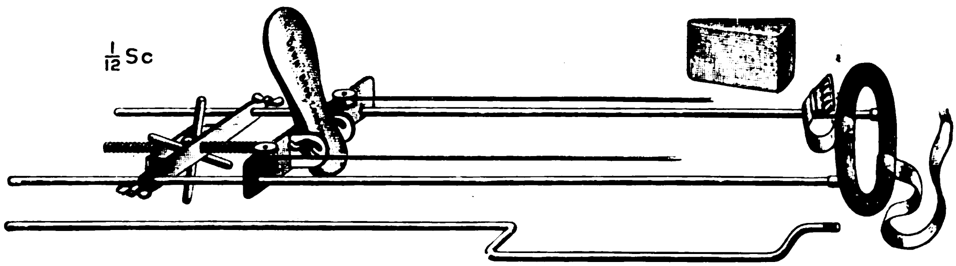


FIG. 223.—The Wallace-Maybury extension splint with Down Bros.' improved mechanism.

The advantage claimed is that extension is steadily applied without imparting any unnecessary movement to the limb.
The splint is supplied with extra cranked bar, as illustrated, for use in case of open wounds, etc., and wedge shaped pad to insert under the outer side of ring to insure bearing on the tuber ischii.

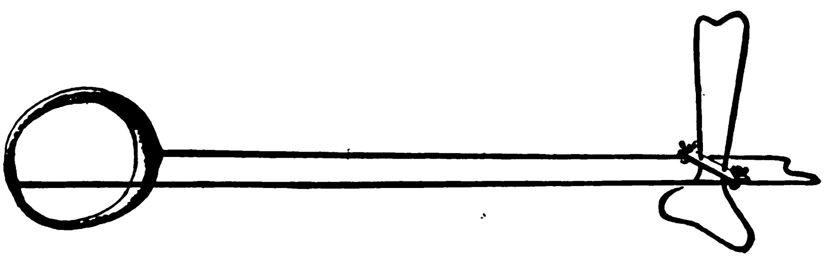


FIG. 224. –Thomas's knee-splint with foot rest attachment (K.W.H.S.D. design).

Length, 40-44 inches. Size of ring from 18-27 inches. The foot-rest can be adjusted to any length of leg, or removed if desired, and can be bent to any angle, so that foot can be slung from top bar of rest.

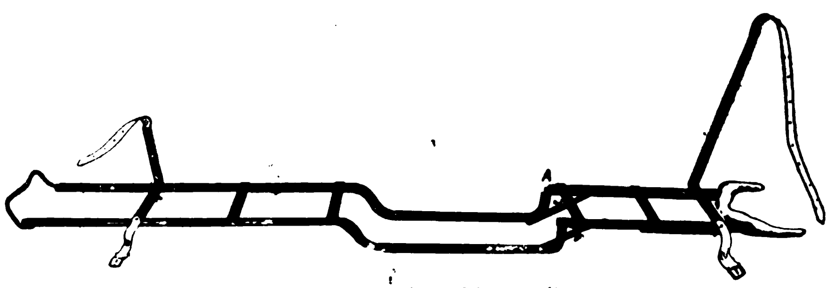


FIG. 225.—Hughes's Liston splint.

This form is interrupted, and if required can be abducted. The shoulder crutch can be adjusted to suit length of patient. Abduction can be obtained at joint A.

that they do not press upon a large vessel. He should also remove all loose spicules of bone that may be in contact with or in the neighbourhood of any large vessel. When the fracture is adequately reduced

and the reduction satisfactorily maintained, a Carrel-Dakin dressing is applied (see Figs. 227, 228). A back-splint is now affixed to steady all, and the patient is returned to bed.

The patient is sent to the base hospital as soon as possible, with the limb slung from a stretcher bar.

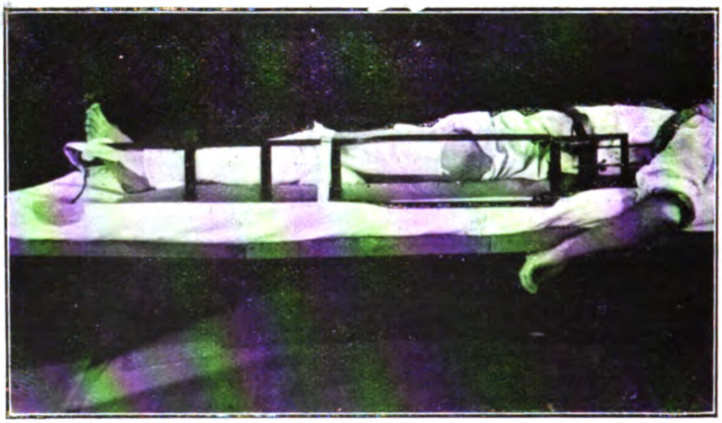


FIG. 226.—Hughes's Liston splint applied, with back splint.

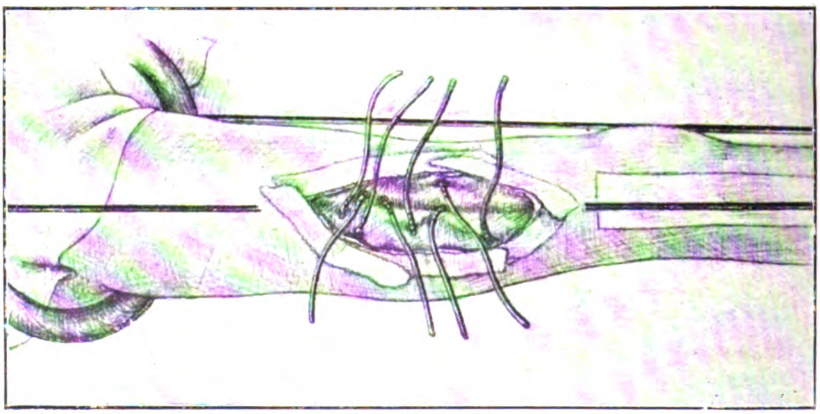


FIG. 227.—Application of Carrel tubes.

C. **At the Base Hospital.**—The dressings are changed on the day after arrival, and the wound inspected. Before removing the dressing it is advisable to slightly tighten up the extension, as there is always a certain amount of give in the material which forms it. The Carrel tubes should be changed, and the new ones should reach to every part of the wound, and especially down to and amongst the fragments of bone. A bacterio-

logical examination as to the number of organisms per field should be made, and sterilisation of the wound proceeded with. As soon as the wound

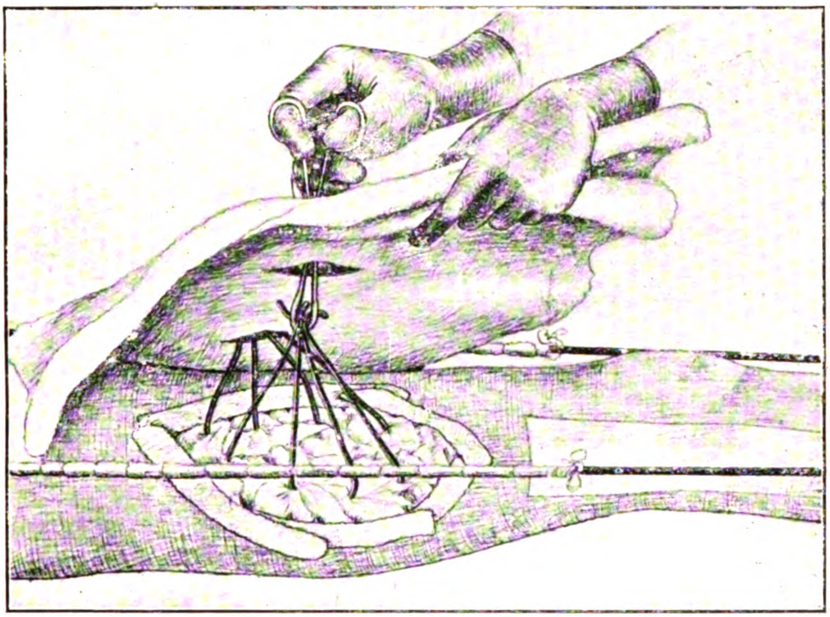


FIG. 228.—Carrel tubes drawn through dressings.

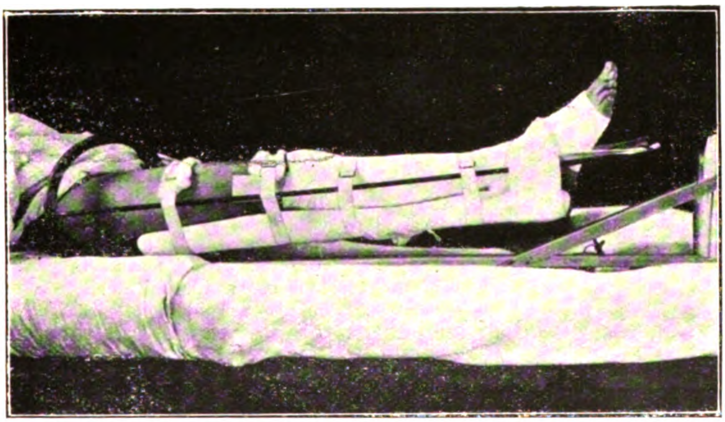


FIG. 229.—Thomas's knee-splint with screw extension applied for case of compound fracture of femur.

Note the back splint and Sinclair's cradle.

is sterile—and this in the case of compound fracture of the femur has varied from the sixth to the twentieth day following injury—the wound is sutured.

At the end of a month the Wallace-Maybury splint is removed and a Thomas's knee-splint (trench pattern, see Fig. 230) is substituted.

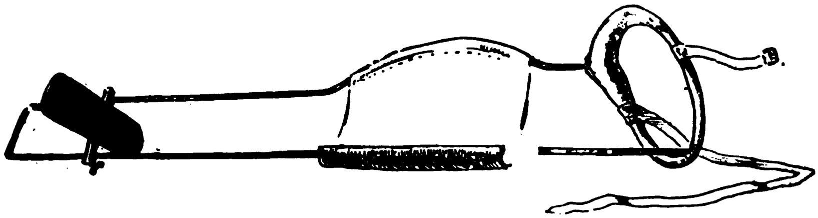


FIG. 230.—Thomas's knee-splint, trench pattern. Shown applied in Fig. 234.

If foot-drop be present, it must be corrected from the start, and the foot must be kept in inversion if the peronei muscles are not paralysed. Foot-drop may be avoided by the use of a foot-piece or apparatus shown in Figs. 231, 232, but its early correction is very important.

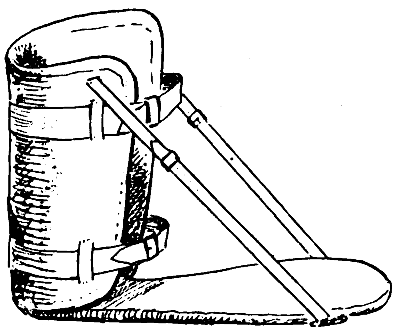


FIG. 231.—Bed boot.
Suitable for cases of foot-drop. For use in bed. Made in papier-mâché and covered with canvas.

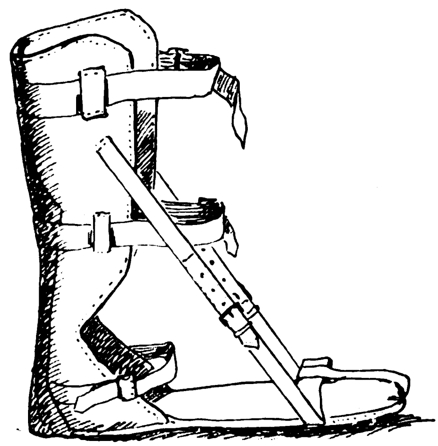


FIG. 232.—Walking boot.
Suitable for cases of foot-drop: (*a*) Made in papier-mâché and block leather for outdoor use; (*b*) made in papier mâché and canvas for bed use.

During the period of sterilisation of the wound and the remaining time spent in bed the thigh will tend to sag, allowing the fractured ends of the bone to unite at an angle. This must be carefully watched for and

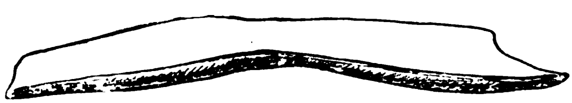
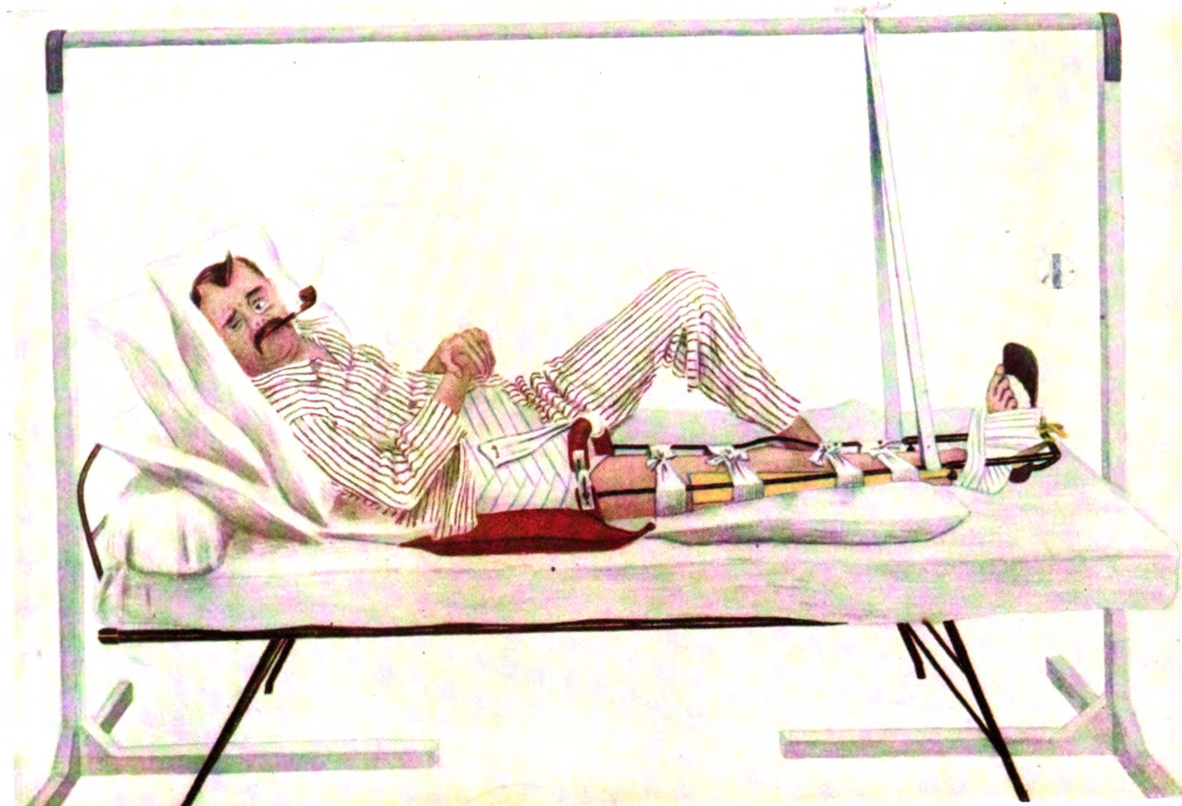


FIG. 233.—Ham-splint.

avoided. It will never happen if the extension is adequately kept up and a back-splint, preferably a ham-splint, is used to support the limb from behind (see Fig. 233).

PLATE VII.



"Thomas" knee splint (trench pattern) applied after removal of Wallace Maybury splint.

To face page 422.

FIG. 234.—Three cases of severe compound fractu e of femur up on crutches at the end of five weeks from date fol!owing injury.

FIG. 235.—A group of cases of severe compound fracture of the femur at the end of eight weeks following injury.

In every case there was union, and in every case movements were daily increasing.

At the end of the fifth or sixth week the patient is allowed up on crutches. The effect of this is to enhance union by the congestion it occasions in the dependent limb.

At the end of the seventh week massage is commenced, and the patient is sent to be fitted with a calliper walking splint, with which he can manage to get about with the aid of a stick.

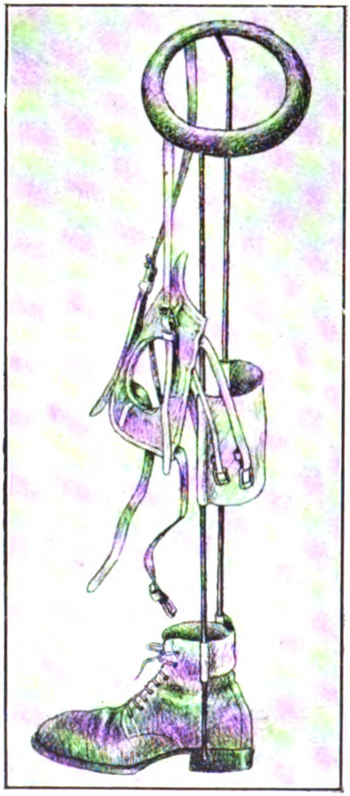


FIG. 236.—Calliper walking splint.

As union occurs, there is excessive formation of callus, due, no doubt, to the comminution and splintering of the bone. This in time is to some extent absorbed.

At the end of three months bony union is firm, and the patient is now allowed to bear weight on the limb. He is then transferred to an orthopædic depot for further massage and exercises.

During the period of sterilisation small emboli may occasionally become detached and lodge in the lung. This may give rise to a slight irritating cough, which usually subsides and causes no further trouble. We have only seen this occur in connection with compound fracture of the femur.

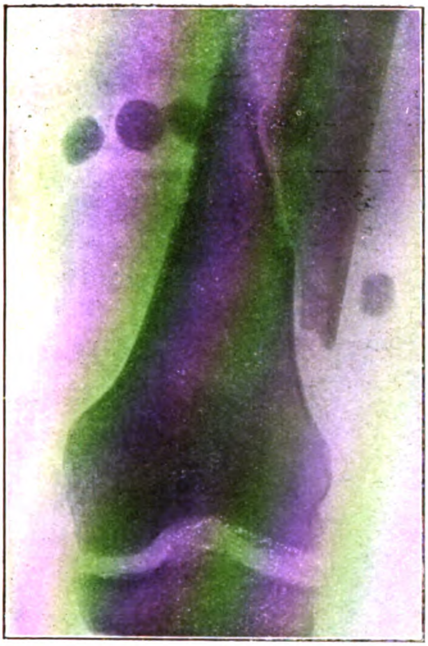


Fig. 237.—Compound fracture of femur associated with secondary hæmorrhage of popliteal artery due to pressure exerted upon it by the lower fragment.

The round shadows are salt tablets.

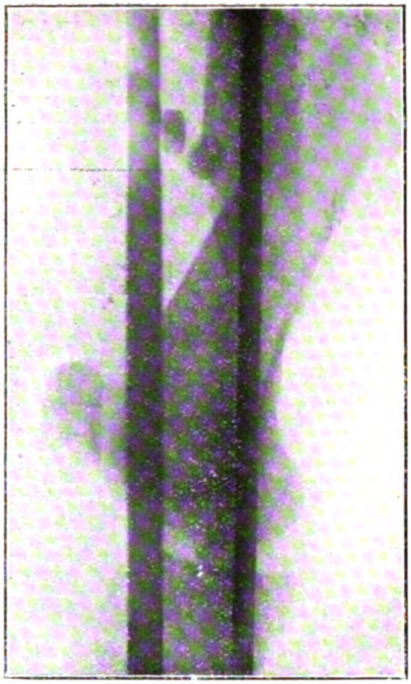


Fig. 238.—Same case as Fig. 237 viewed laterally.

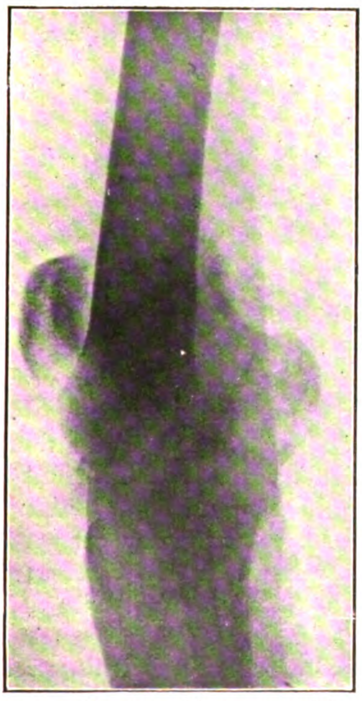


Fig. 239.—Fracture of lower end of femur involving knee-joint, resulting in firm ankylosis.

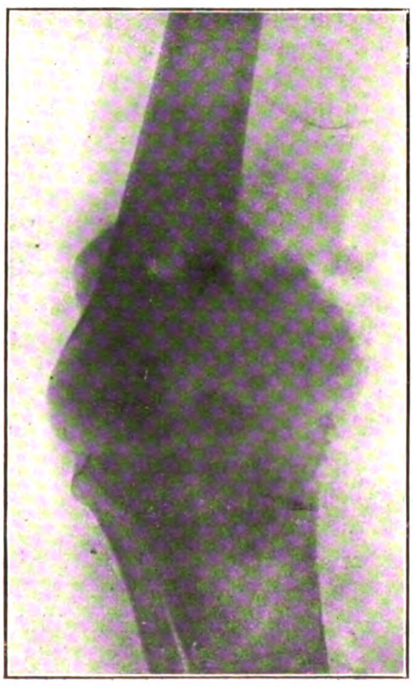


Fig. 240.—Same case as Fig. 239 (antero-posterior view).

Secondary hæmorrhage, septicæmia, and osteomyelitis have occurred exceedingly rarely since the adoption of the Carrel-Dakin method;

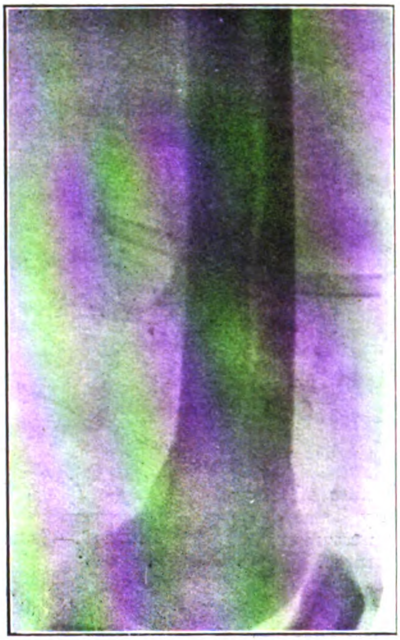


FIG. 241.—Fissured fracture of lower third of femur involving the knee-joint.

but should they occur, treatment recommended in other chapters dealing with these complications should be carried out.

We have never found it necessary to resort to plating or bone-grafting.

Tibia and Fibula.

Compound fracture of the tibia may or may not involve the ankle or knee joints, and fracture of the tibia and fibula may exist separately or in combination. Fracture of the tibia may range from a perforation or fissure to extensive comminution, whereas fracture of the fibula often consists in a small breach of continuity without excessive comminution (see Figs. 242, 243). Compound fracture of the lower end of the fibula usually shows a greater degree of comminution and involves the ankle-joint.

Severe laceration of the soft structures may accompany compound fracture of the bones of the leg, and frequently the anterior tibial artery and nerve or the posterior tibial artery, but rarely the posterior tibial nerve, are lacerated and divided.

Fractures of the lower third of the tibia are extremely difficult to keep satisfactorily immobilised and in position during sterilisation.

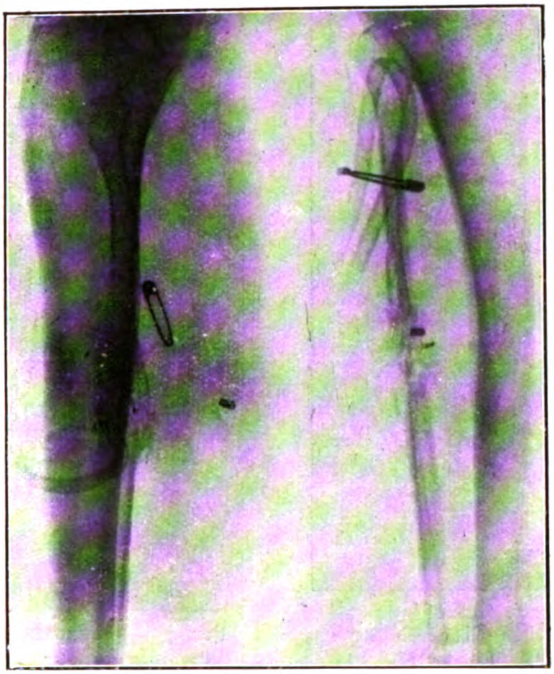


FIG. 242.—Compound fracture of the fibula, with small breach in continuity and little comminution.

FIG. 243.—Compound fracture of the fibula, with small breach in continuity and little comminution.

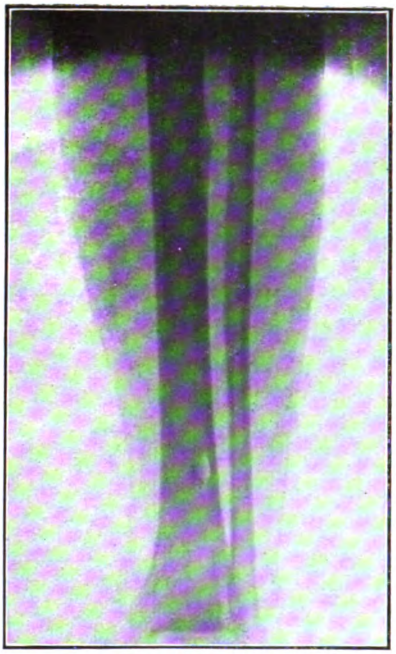


FIG. 244.—Gutter fracture of lower end of tibia without loss of continuity and without fissure.

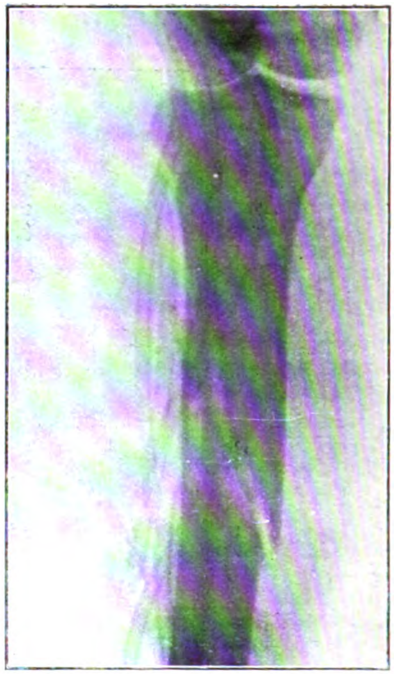


FIG. 245.—Fissured fracture of tibia.

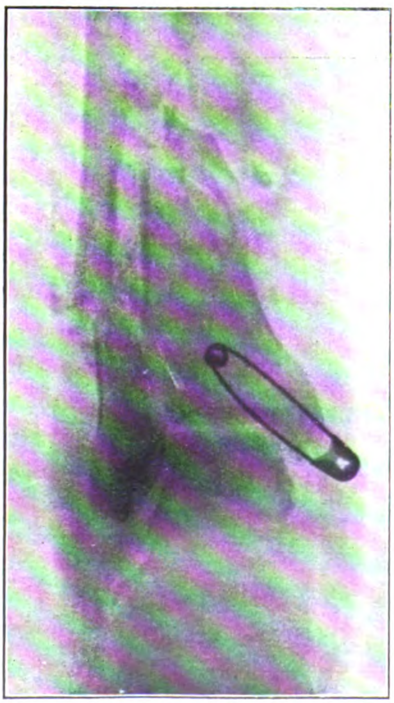


FIG. 246.—Comminuted fracture of the lower end of the tibia and fibula involving the ankle-joint.

FIG. 247.—Same case as Fig. 246, viewed laterally.

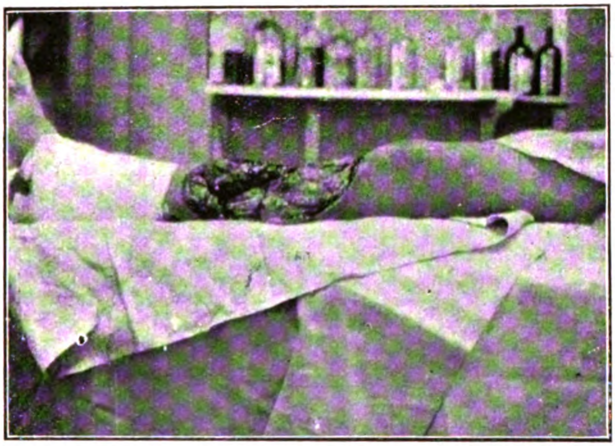


FIG. 248.—Severe lacerated wound of leg involving fracture of the tibia.

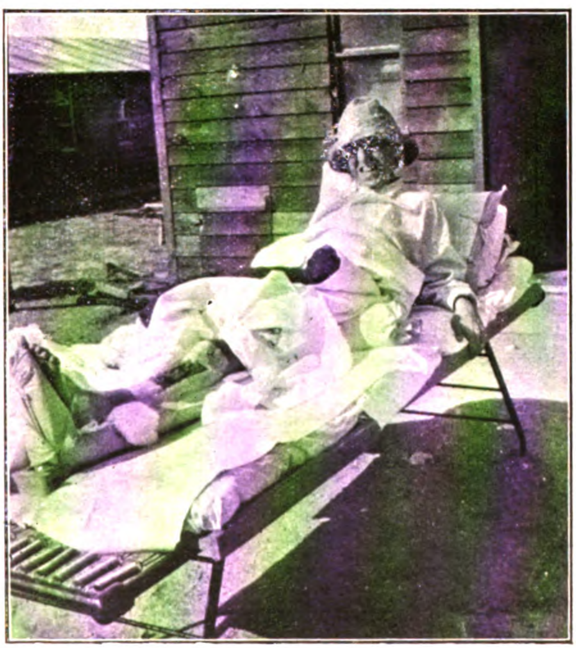


FIG. 249.—Same wound as Fig. 248 undergoing sun treatment.

TREATMENT.

A. **On the Battlefield.**—The fractured limb should be thoroughly immobilised by means of one posterior and two lateral splints made from pieces of a ration box. Under no circumstances whatever should any attempt be made to reduce the fracture, but after applying a shell dressing it should be splinted as it exists. The wounded man should be carried to the motor ambulance, and transferred to the casualty clearing station with as little delay as possible. He may be given a quarter of a grain of morphia to relieve pain. If the limb is irretrievably damaged, amputation should be performed, at either the advanced dressing station or the field ambulance.

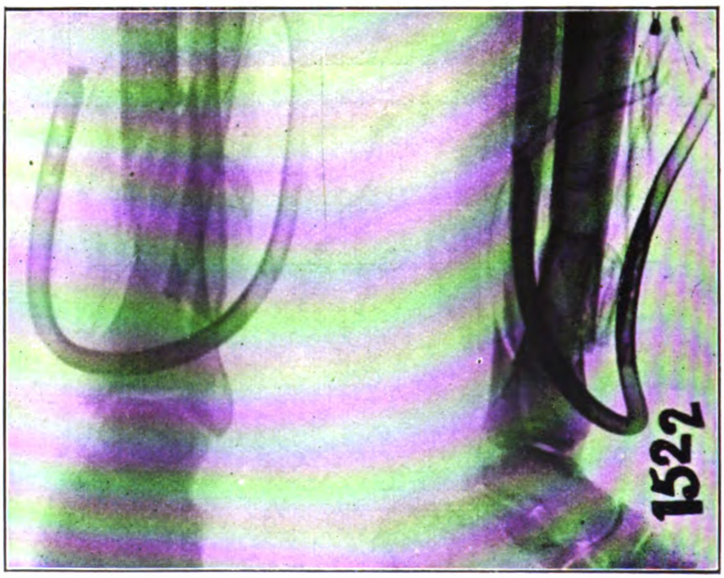


FIG. 250.—Fracture of lower end of tibia and fibula undergoing sterilisation.

B. **At the Casualty Clearing Station.**—Shock occasioned by injuries of the leg is not usually severe; consequently the patient may be operated upon soon after his arrival at the casualty clearing station. After anæsthesia is induced, the splints and dressing should be removed, the pubes and lower extremity shaved, and the skin thoroughly cleaned. Toe-nails should be cut short and the foot cleaned with turpentine. When this is complete, the surgeon should excise the wound, removing detached and useless pieces of infected bone. Hæmostasis should be secured and any divided nerve sutured, if practicable. When this is complete, extension is affixed by means of sterile gauze and Page's glue (see Fig. 251). Extension can be taken directly from the foot by means of a leather spat, but

we have found this apparatus unsatisfactory. A Thomas's knee-splint is now applied, and the extension is regulated by means of a screw adjustment affixed to the lower bar. The extension is tightened until the bones

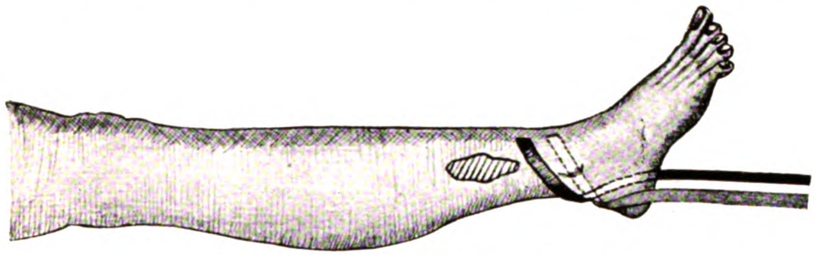


FIG. 251.—Gauze fixed by Page's glue, for extension.

are in position, when a Carrel-Dakin dressing is put on. A ham-splint is combined with the Thomas's splint, and this steadies all. The patient is then transferred to the base hospital.

C. **At the Base Hospital.**—Continuous sterilisation of the wound is carried on until the bacteriologist reports the wound sterile, which is usually from the tenth to the seventeenth day. At this stage secondary suture is performed, and the limb is now put up on a back-splint and foot-piece with lateral splints. If the fracture be situated in the lower third of the tibia, union is usually delayed, and it is difficult to retain satisfactory apposition. Under these circumstances, if the wound is sterile, the fracture may be fixed either with plates or bone-grafts (see Figs. 252, 253). The cases in which we found it necessary to use plates did well, and no harm came of their use, as union and healing occurred.

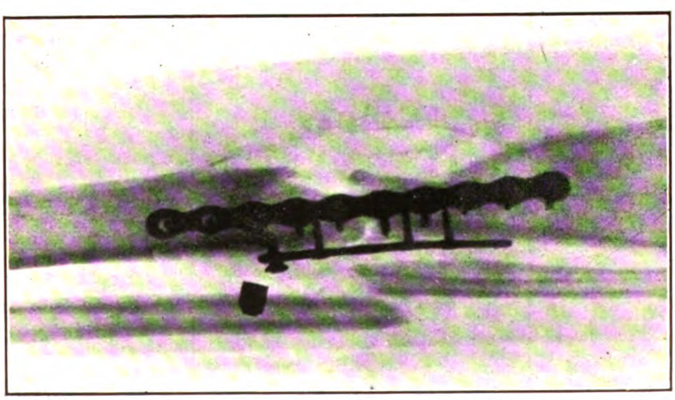


FIG. 252.—Compound comminuted fracture of lower third of tibia plated prior to secondary suture.

The stitches are removed on the tenth day, and the limb is kept on a back-splint and foot-piece for another fortnight. At the end of this period some union has usually taken place, and massage and movements

are begun. The limb is put back on the splint *with the foot at a right angle and inverted.* The patient is allowed up on crutches, with the injured

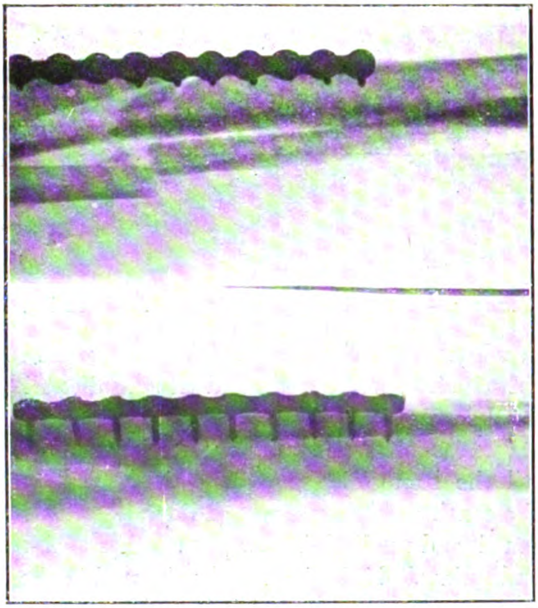


FIG. 253.—Compound fracture of lower third of tibia plated prior to secondary suture.

FIG. 254.—Compound fracture of tibia sterilised by the Carrel-Dakin method. Patient up early on crutches, with fractured leg slung from neck.

limb kept off the ground by means of a strap placed round his neck, on the second or third day following the removal of the stitches. By this

means a passive congestion is brought about in the wounded limb, which materially hastens the formation and consolidation of the callus.

At the end of the seventh or eighth week following injury the splint may be omitted, the patient still going about on crutches and putting no weight on the limb. Should foot-drop be present, an apparatus for its correction must be worn.

At the end of the tenth week the patient is fitted with a boot crooked along the inner side of the heel and sole, and is now allowed to put some weight on the limb.

At this period he leaves for the orthopædic depot with full movements of the limb, and receives further massage and exercises.

Tarsus and Metatarsus.

Fractures of the tarsal and metatarsal bones were at one time the most difficult of all to sterilise. This is explained by the complex nature of the

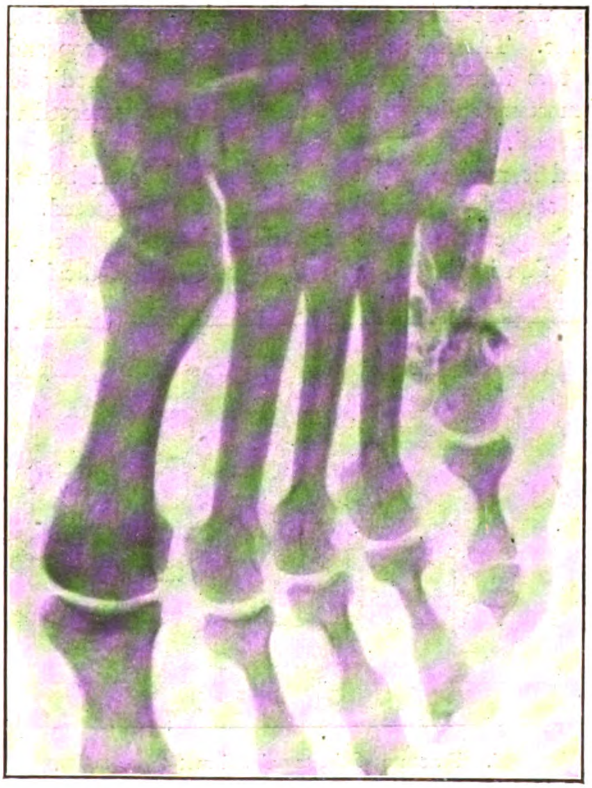


FIG. 255.—Compound comminuted fracture of the fifth metatarsal bone.

synovial cavity surrounding them, and by the fact that in our earlier cases we were too conservative. Fractured bone, which later proved to be useless, was left *in situ*, sterilisation was exceedingly slow owing to the diffi-

culty experienced in getting the antiseptic to every part of the complex wound, suppuration was prolonged, and excessive formation of fibrous tissue, with irremediable stiffness and incapacity, followed. Profiting by the experience and advice of the French and Italian surgeons, we adopted new methods, which gave striking results.

Treatment.

A. **On the Battlefield.**—The boot should be removed, and after application of the field or shell dressing, the foot should be fixed at a right angle by means of splints made from pieces of ration box. The patient should be carried to the advanced dressing station. If the foot is hopelessly crushed and its vitality destroyed, amputation should be performed without delay at the field ambulance. Morphia (gr. $\frac{1}{4}$) may be given before the patient is sent to the casualty clearing station.

B. **At the Casualty Clearing Station.**—After anæsthesia has been induced, the limb should be shaved and washed. The foot is now scrupulously cleaned, the toe-nails are cut short, and the sole of the foot cleaned with turpentine. The nails are scrubbed with ether soap and the space between the toes thoroughly washed, and finally cleaned with ether or biniodide of mercury and spirit while the wound is protected with a swab wrung out of eusol.

The wound is now wholly excised, damaged tarsal bones should be removed, and severely fractured metatarsal bones resected. The metatarsal bone of the great toe should, if possible, always be spared, owing to the important rôle that it plays in maintaining the arch of the foot.

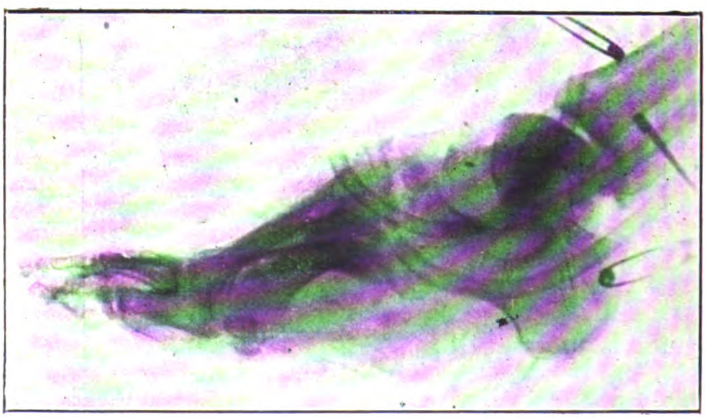


Fig. 256.—Fracture of the tarsal and metatarsal bones. Damaged bone has been resected, and sterilisation is in progress.

After procuring hæmostasis, a Carrel-Dakin dressing is applied, the foot is put up at a right angle and kept inverted, and nursed on a Robert Jones's crab splint. The patient is then sent to the base.

C. **At the Base Hospital.**—Sterilisation of the wound is carried out until the bacteriologist reports it fit for secondary suture. If, during sterilisation, further pieces of useless bone become obvious, they must be removed without delay. If stiffness and incapacity are to be avoided, sterilisation must be rapid and secondary suture performed early, for the longer the wound remains open the greater will be the incapacity. Since adopting the principle of free removal of damaged bone in the case of the foot, sterilisation has been rapid and easy, and excellent function with the minimum of stiffness has resulted.

FIG. 257.—Compound fracture of second metatarsal bone and middle cuneiform bone. Damaged bone resected. Wound healed by primary union after secondary suture on the twelfth day following the infliction of the injury. Function and movements perfect.

After secondary suture has been performed, the foot must again be *put up at right angles and inverted.* The sutures are removed on the tenth day and the patient is allowed up on crutches with his foot, which is still kept inverted and at right angles, slung off the ground. A fortnight later he is fitted with a boot crooked along the inner side of the sole and heel, and at the end of six weeks—that is, three weeks after the removal of the stitches—he may be allowed to walk in his newly fitted boot with the aid of a crutch or stick.

The Scapula.

Fracture of the scapula has occurred with great frequency during the present war, and is often associated with penetrating or perforating wounds of the chest. The bone may be either cleanly perforated or comminuted. The body of the scapula is the part of the bone most frequently involved, and very rarely does a fracture of the scapula communicate with the shoulder-joint.

Treatment.

A. **On the Battlefield.**—A dressing should be applied, and the arm bound securely to the side. If the chest is involved, the patient should be carried out of the line ; if, however, the chest has escaped, he can walk.

B. **At the Casualty Clearing Station.**—Treatment will depend upon the result of the X-ray and the nature of the wound of the soft parts. If the wound of entry be small and the chest be penetrated, it is best to adopt expectant treatment and to treat the chest condition. If, on the other hand, the wound in the back be lacerated, the chest often seems to escape penetration, and the missile will usually be found between the scapula and chest wall. In the latter case operation is necessary. The wound must be excised, broken pieces of the body of the scapula should be removed, and the foreign body extracted. A Carrel-Dakin dressing is applied, and the patient evacuated to the base with the arm bandaged to the side.

C. **At the Base Hospital.**—When the wound is reported sterile, secondary suture should be performed. The stitches are removed at the end of the tenth day, and at the end of another week movements are commenced and the patient encouraged to move his arm. This class of case has given highly satisfactory results, the majority rapidly regaining full range of movement and being discharged to perform some duty on the lines of communication. It is very essential that wounds in this position should not be allowed to heal by granulation, for by this means a cicatrix results, which will in all probability prevent the soldier from carrying his equipment.

The Clavicle.

Compound fracture of the clavicle may be associated with wounds about the root of the neck or penetrating wounds of the chest. A number of cases die on the battlefield as a result of injury of the large vessels which lie in near relation to this bone. The commonest site of fracture of the bone is the middle third. Displacement is often considerable, but extensive comminution is not common.

Treatment.

A. **On the Battlefield.**—The arm should be bandaged to the side and the shoulder elevated, either with a puttee or a triangular bandage. A dressing should be applied and the wounded man sent to the advanced dressing station.

B. **At the Casualty Clearing Station.**—The wound should be excised, the fractured ends of the bone manipulated into position, and a Carrel-Dakin dressing applied. Should the X-ray show the presence of a foreign body in the root of the neck, it should be removed. These wounds are

sometimes associated with damage of the brachial plexus, but it is not wise at this stage to interfere with the nerve trunks. Should wrist-drop be present, it must be corrected.

The arm is now put up by Sayre's method, and the patient evacuated to the base.

C. **At the Base Hospital.**—As soon as the wound is sterile it should be sutured. If the fragments of bone show a tendency to keep apart it is quite justifiable, when the wound is sterile, to apply a plate before performing secondary suture. The stitches are removed at the end of the tenth day,

FIG. 258.—Compound fracture of the clavicle in its middle third.

but the arm is kept up in bandages or other suitable apparatus for another three weeks or a month. If at the end of this time union has occurred, the plate may be removed, and after the wound has healed the patient may go about with his arm in a sling. As soon as union is firm the sling can be discontinued and the patient may use his arm.

The Humerus.

Compound fracture of the humerus has been of frequent occurrence during the present war, and the fracture in the majority of instances has been both extensive and comminuted. Either the shoulder or elbow joints may be involved, and injury of the musculo-spiral nerve with wrist-drop has been a common complication. In several instances the

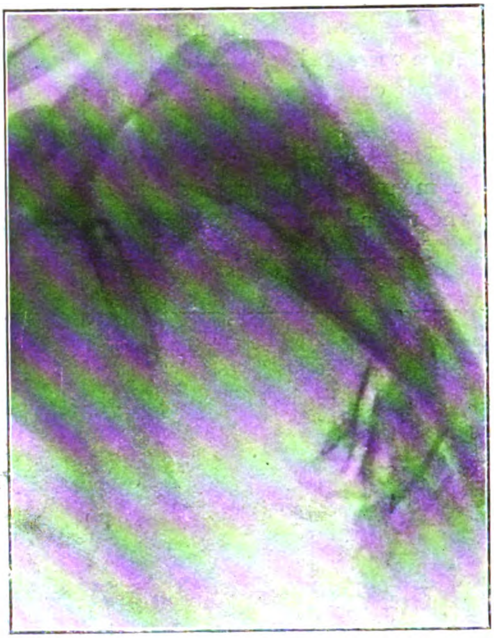


FIG. 259.—Compound comminuted fracture of the upper end of the humerus.

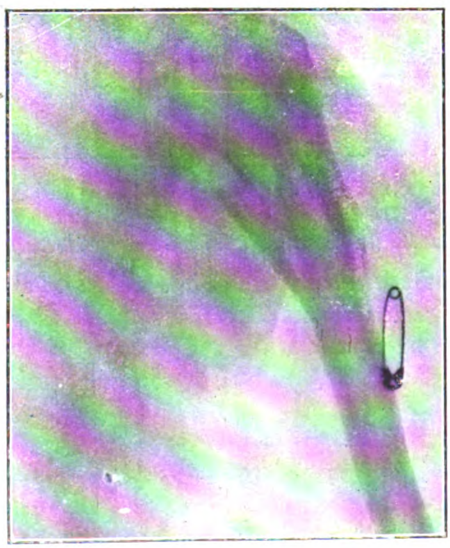


FIG. 260.—Same case as Fig. 259, a month after injury.

Sterilisation and secondary suture were early performed, and good movement resulted.

brachial or superior profunda arteries have been torn and necessitated ligature, yet in this connection we have never seen gangrene of the arm result. The soft structures are commonly lacerated and highly infected. A rifle bullet traversing the limb may leave a small wound of entry and exit, and yet cause excessive comminution of the bone.

Osteomyelitis, septicæmia, and secondary hæmorrhage have been extremely rare complications of injuries of this bone since the adoption of the Carrel-Dakin system of treatment, and the wounds as a whole sterilise easily.

FIG. 261.—Compound fracture of humerus undergoing sterilisation. Result: good union and excellent function.

The remote complications are stiffness and limitation of movement both at the shoulder and elbow joints, but since rapid sterilisation and secondary suture have been carried out, with the consequent minimal amount of fibrous tissue formation and matting of the soft structures, stiffness and limited movement are becoming events of the past.

A rare and later complication of compound fracture of the humerus has been *reflex paralysis*. The symptoms of this condition are an increased irritability of the intrinsic muscles of the hand, especially the interossei. These muscles, if tapped, contract; further, the deep reflexes in the tendons surrounding the wrist are all increased. The skin of the hand is blue and the local temperature subnormal. If the hand is allowed to hang down

it becomes hyperæmic, painful, and local perspiration follows. The condition is not understood, but it is apt to follow ligature of the brachial artery or damage to the large nerve trunks. The origin of the complaint is supposed by some to be central, and confined to the sympathetic nerves, a condition of arterio-spasm resulting. French surgeons have attempted a cure by exposing the main artery and stripping it to an extent of half an inch of its sympathetic coat. The artery, when found, is exceedingly small in calibre and the operation is difficult to carry out satisfactorily, and up to the present no results from such a procedure have been reported. In some respects the condition resembles erythromelalgia.

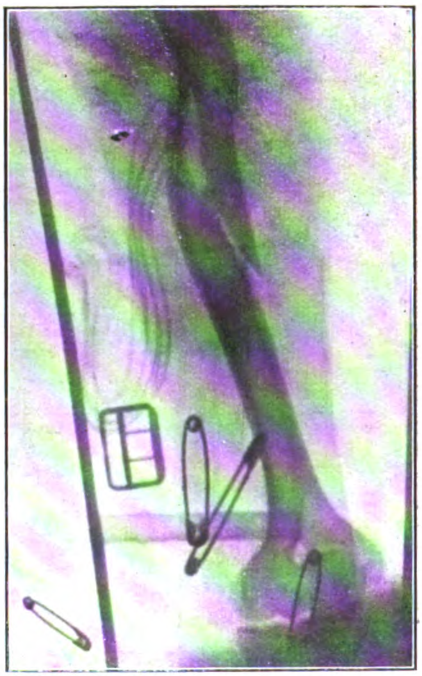
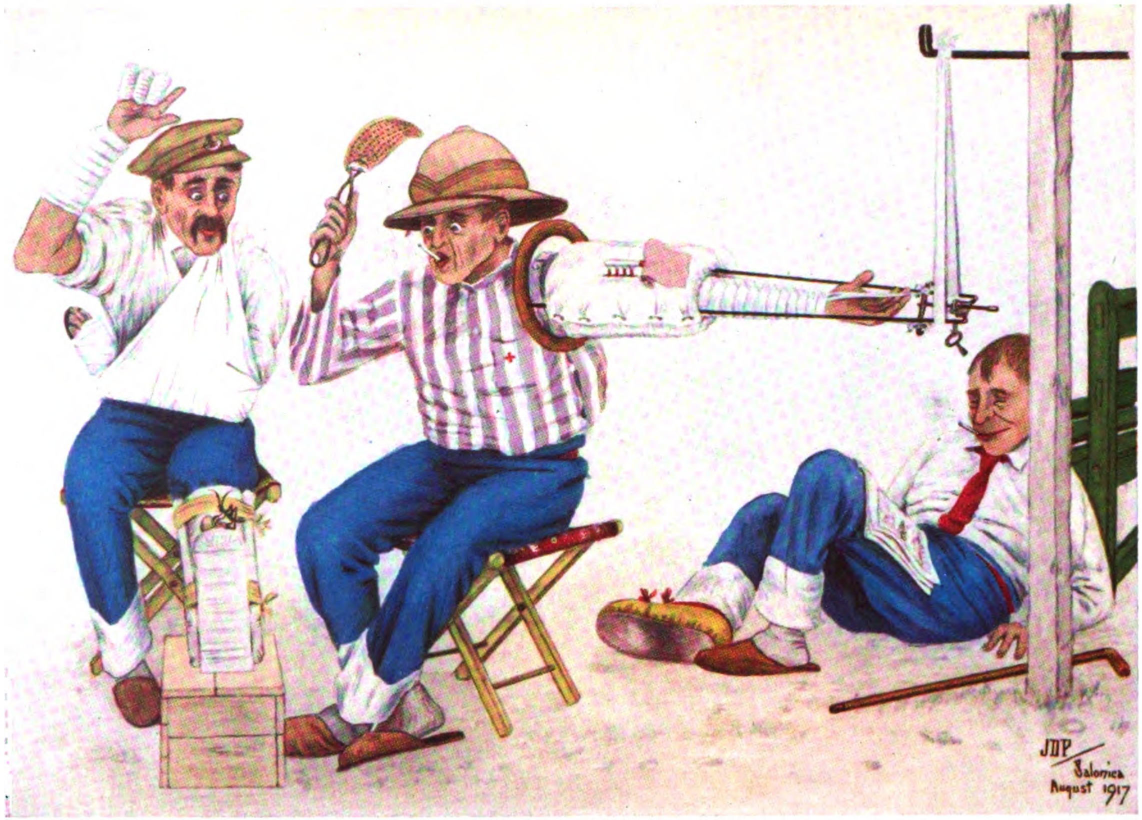


FIG. 262.—Compound comminuted fracture of humerus undergoing sterilisation.

TREATMENT.

A. **On the Battlefield**.—After applying a dressing, the arm should be bandaged to the side and the forearm across the front of the chest. If hæmorrhage be present, the bleeding vessel must be picked up and tied. Unless absolutely necessary, a tourniquet should not be employed. At the advanced dressing station satisfactory hæmostasis should be secured, and under no circumstances should the patient be sent on to the field ambulance with a tourniquet applied. Nothing further need be done at the field ambulance unless the limb is hopelessly mangled, when amputation should be performed prior to transit to the casualty clearing station.

PLATE VIII.



This Plate illustrates three cases. One patient has severe compound fracture of the humerus, patient up four days after admission to base hospital. Wound still undergoing sterilisation. One patient has compound fracture of tibia and wrist drop. The third patient has a damaged foot.

To face page 441.

B. **At the Casualty Clearing Station.**—After thoroughly shaving and cleaning the limb and axilla, the wound should be completely excised and any detached and dead pieces and spicules of bone removed. The foreign body must be found and extracted. A previous X-ray will show its position and the nature of the damage done to bone. Divided nerve trunks, if present, should be sutured. Extension is now applied by means of sterile gauze and Page's glue. This may be applied to the limb anteriorly and posteriorly or laterally, depending upon the position of the wound. A straight arm-splint (Thomas's) is now applied, and extension brought about by means of a screw adjustment which is attached to the lower bar of the splint. Extension is now applied while the surgeon manipulates the fragments into position. As soon as reduction is effected, the surgeon should take care that the fractured ends of the bone are clear of the main vessels and nerve trunks, and that all detached spicules of bone are removed

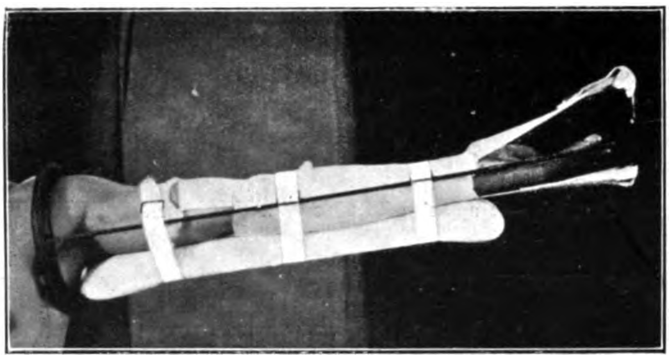


FIG. 263.—Compound fracture of the humerus put up on straight arm-splint with extension.

from their immediate neighbourhood. This done, a Carrel-Dakin dressing is applied, the tubes being inserted down to and amongst the fragments of bone. Under no circumstances should a Carrel's tube be allowed to rest against an artery or a nerve.

A back-splint is now applied, and *the forearm maintained in a position of full supination* (see Fig. 263).

C. **At the Base Hospital.**—When the wound is reported bacteriologically sterile it is submitted to secondary suture, and the stitches are removed on the tenth day. The arm is kept in extension for a month, at the end of which period the wound is healed and some union in the bone has taken place. The patient is allowed up while the wound is undergoing sterilisation—that is, on about the fourth day after admission to the base hospital. Plate VIII., though slightly inaccurate and exaggerated, will give some idea of the way in which these patients amuse themselves. They can either sit up in a chair with the splint suspended from some suitable contrivance, or they may walk about with a comrade supporting the

splint at a right angle to the body. Fractures and wounds both heal and sterilise far more quickly when the patients are up, the patients both

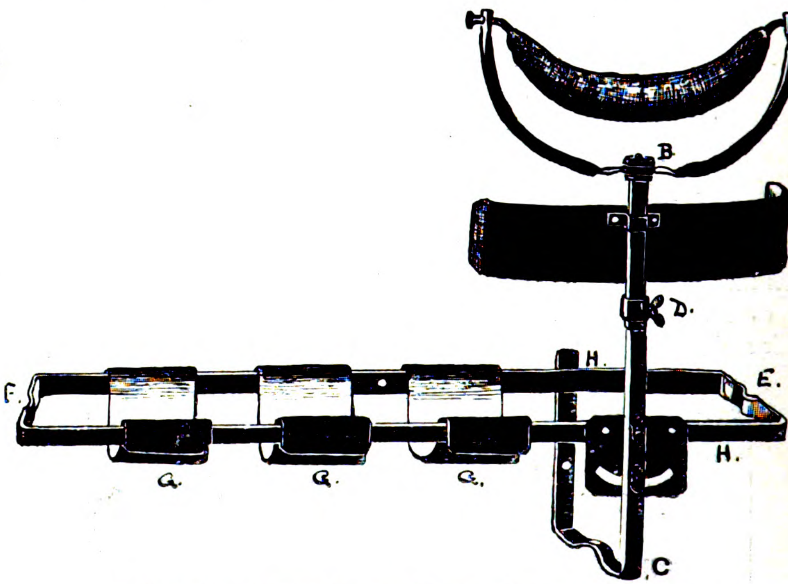


FIG. 264.—Hughes's adjustable splint for upper extremity.

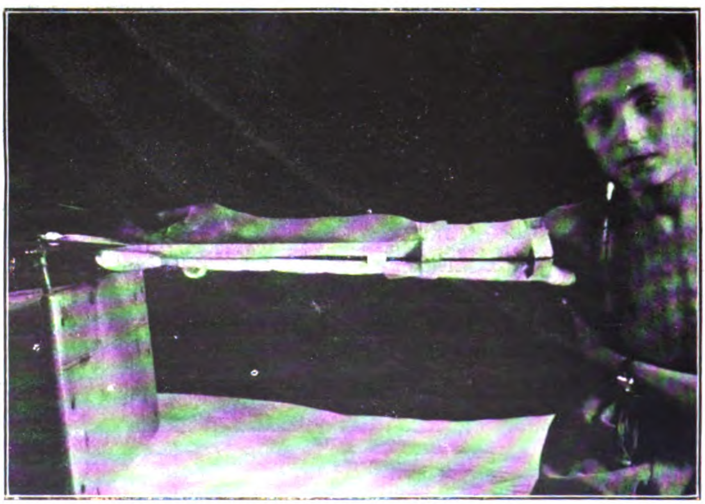


FIG. 265.—Straight arm-splint, with lateral extension applied to upper arm. The back-splint is maintained.

eat and sleep better, the nursing is made lighter, and the whole outlook is generally more cheerful for all concerned.

At the end of a month the straight arm-splint and extension are removed

under an anæsthetic. Passive movements of the shoulder and elbow joints are performed once in order to be sure that there is no limitation of movement, and the arm is put up in another kind of splint. Should union still be insecure, the splint shown in Fig. 264 may be employed, or the straight arm-splint is still retained with extension applied laterally to the upper arm only (see Fig. 265). By this means movements at the elbow-joint are permitted daily, while the extension on the upper arm remains undisturbed (see Fig. 266).

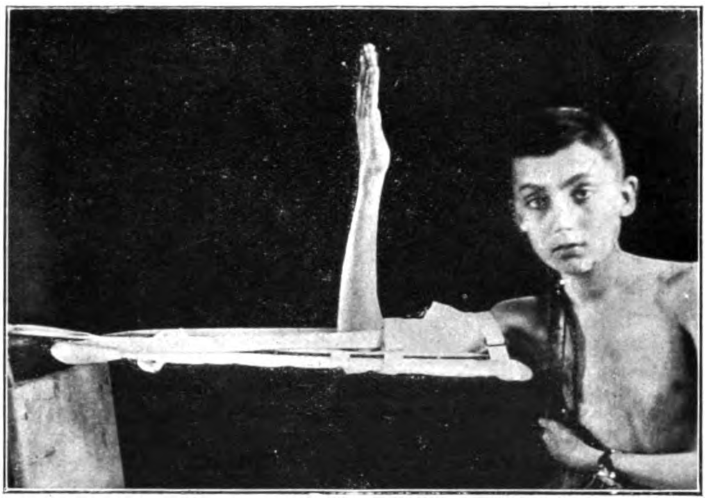


FIG. 266.—Movements at elbow-joint while the extension on the upper arm is not interfered with.

The splint shown in Fig. 264 was devised by one of us for the treatment of all fractures involving the upper extremity. A padded crutch hinged at *A* occupies the axilla. At *B* is another joint permitting of horizontal movements. The distance from *B* to *C* is adjustable by means of a screw, *D*. Extension for the upper arm is taken between the padded crutch and the bar *C*. *EF* is a horizontal frame hinged at the points *H*. Extension in the case of a fractured forearm is taken between the points *E* and *F*, while the forearm is supported in full supination by metal troughs, *G*. This splint then allows of abduction at the shoulder-joint by means of the joint *A*, rotation of the shoulder-joint at joint *B*, and flexion and extension of the forearm at the joint *H*.

After removing the straight splint and extension and performing movements as described, the forearm is put up at a right angle to the upper arm, *and must still be maintained in full supination*. If the latter precaution is not taken much disability will result, because the forearm becomes fixed in pronation, and this is very difficult to overcome. Unfortunately, to-day we see many convalescing cases of fracture of the upper arm and forearm walking about with the forearm in full pronation, and in which any attempt at

passive supination causes much pain—in fact, supination is almost impossible. This serious fault requires much time and patience for its correction, if indeed such is possible. The apparatus shown in Fig. 267 is one

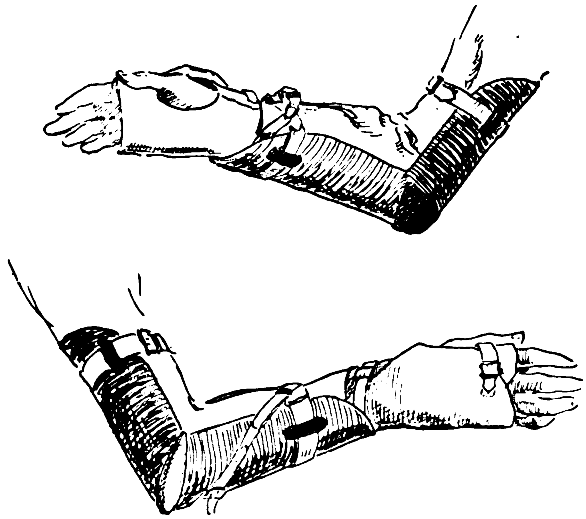


FIG. 267.—Supinator arm-case.
Used to induce supination of the hand by means of elastic band. Made in papier-mâché and covered with khaki.

of the best of its kind for correcting the condition. At the end of the fifth week massage and passive movements at the shoulder and elbow joints can be commenced. The passive movements can all be carried out while the arm is in the splint shown in Fig. 264.

FIG. 268.—Two cases of compound fracture of humerus (see Figs. 260, 261), showing extension and pronation of forearm.

At the end of the sixth or seventh week union is usually sound, and the splint may be omitted, the patient using a sling.

At this stage the patient may use his arm to do small jobs about the ward, and at the end of the eighth week he leaves the hospital for a convalescent depot with good movements in the injured limb.

FIG. 269.—Same two cases as shown in Fig. 263, showing flexion of forearm and supination.
These cases are ready to proceed to the convalescent depot.

Fractures of the humerus in the neighbourhood of the elbow-joint, after sterilisation and suture, may be put up on a Robert Jones's splint

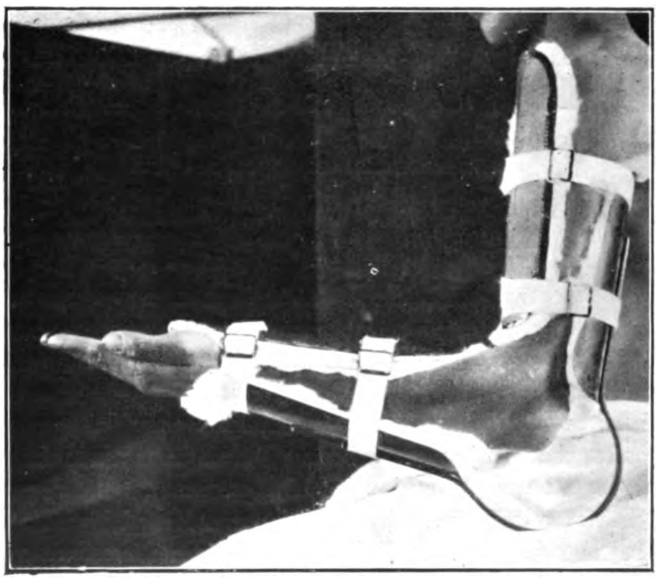


FIG. 270.—Robert Jones's splint for fracture involving the elbow-joint applied.

devised for injury involving the elbow-joint (see Fig. 270). We prefer, however, to use the splint shown in Fig. 264 for all cases.

Should wrist-drop be present, it must be corrected *from the start by means of a splint which should maintain an uninterrupted dorsiflexion* (see Plate VIII., left-hand figure).

Fig. 271.—Group of five cases of compound fracture of the humerus. Good union and movements were present in all. The photograph was taken five weeks after injury.

The Radius and Ulna.

Compound fracture of the bones of the forearm may occur separately or in combination. They may be associated with damage to nerves and arteries, and the wound of the soft structures may be small and penetrating or perforating, or it may be lacerated. Wounds of the forearm involving bone may be associated with most troublesome hæmorrhage from the interosseous arteries. Injury of the bones of the forearm has in the majority of instances been severe, comminution of a greater or lesser degree being present. The secret of success is, as before stated, rapid sterilisation and secondary suture, for the longer these wounds are allowed to suppurate the greater will be the amount of fibrosis and scar tissue, and consequently the greater the resulting stiffness and incapacity. A complication always to be avoided is cross-union of the fractured bones.

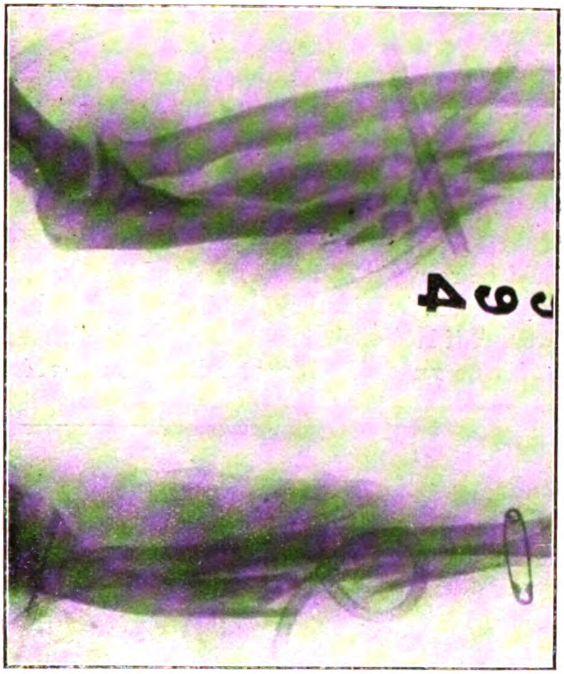


FIG. 272.—Compound comminuted fracture of the ulna undergoing sterilisation.

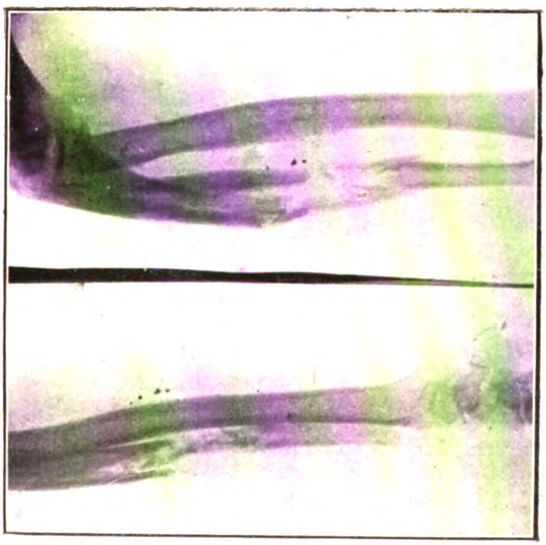


FIG. 273.—Same case as Fig. 272 one month after injury, after secondary suture was performed and the wound healed.

Note new bone-formation, with union of the fragments.

Treatment.

A. **On the Battlefield.**—After application of the dressing the arm should be put up on a straight splint, and the patient sent at once out of the line. At the field ambulance nothing further need be done unless the forearm is hopelessly mutilated, in which case amputation should be immediately performed.

B. **At the Casualty Clearing Station.**—After anæsthesia has been induced the splint should be removed and the arm and axilla shaved and washed. The finger-nails should be cut short, and the hand and nails scrubbed clean. The wound, if lacerated, should now be excised, all detached and useless pieces of bone removed with the missile, hæmostasis secured, and

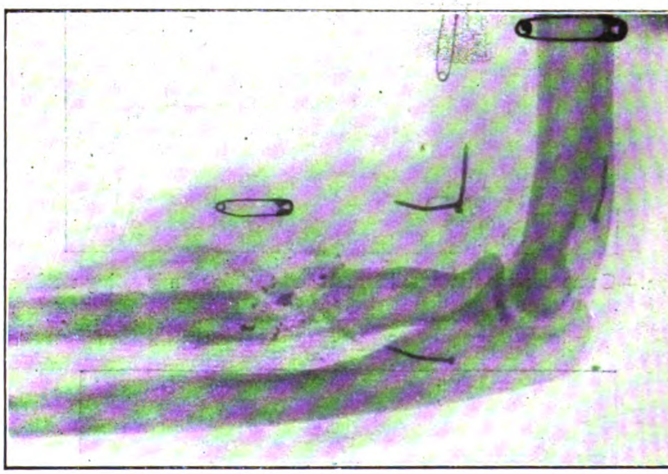


Fig. 274.—Compound comminuted fracture of the radius undergoing sterilisation. Wound was sutured at the end of twelve days after injury. Union occurred, and perfect function of the forearm.

extension applied. We have always used a Thomas's straight arm-splint for these fractures, applied in exactly the same way as for fracture of the humerus, the extension, of course, being taken from below the site of fracture. The surgeon should be satisfied that reduction is complete, and that all rough fragments of bone have been removed from the neighbourhood of the bloodvessels and nerves, before he applies the Carrel-Dakin dressing. Any divided nerves should, if practicable, be sutured. *The forearm must occupy a position of complete supination.*

C. **At the Base Hospital.**—Secondary suture is performed as soon as the wound is bacteriologically sterile, which is usually on about the tenth or twelfth day following injury. The forearm is kept in extension and in full supination for a month. The patient may get up three or four days after arrival at the base hospital. At the end of a month the straight arm-

splint is removed under an anæsthetic, and the splint shown in Fig. 264 is substituted. Extension is maintained if the fracture is not consolidated. At the end of six weeks the extension is removed, massage is commenced, and the fracture is put up on anterior and posterior splints *with the arm still in full supination.* Movements at the wrist and elbow joints should be encouraged, and at the end of the seventh week the patient may begin to use the arm. Should wrist-drop be present, it should be corrected from the start, and this correction *must be kept up uninterruptedly.*

FIG. 275.—Compound comminuted fracture of the radius after secondary suture. Result was perfect union and good function.

The trouble in these cases seems to lie in a contracted condition of the pronator quadratus, but if the forearm is kept from beginning to end in full supination this difficulty will be overcome. At the end of the eighth week the patients leave hospital for the orthopædic depot.

Carpus and Metacarpus.

Wounds of the carpus and metacarpus may range from a simple perforation involving one or more bones to large lacerated wounds complicated by fracture of several bones and damage of nerves and arteries. The nerves most frequently implicated are the median or ulnar, and the arteries most likely to be divided are the radial and ulnar, if the wound be about the wrist, or the palmar arches if it involve the hand.

TREATMENT.

Treatment aims at rapid sterilisation combined with conservatism. No more bone than is absolutely necessary should be removed, and in this

respect treatment differs from that recommended for corresponding wounds of the tarsus and metatarsus. Fortunately, wounds about the hand, if early and thoroughly excised, sterilise quickly by the Carrel-Dakin system, and on the whole most gratifying results have been obtained.

A convenient splint for wrist wounds is that shown in Fig. 276, the wrist being kept throughout treatment in dorsiflexion.

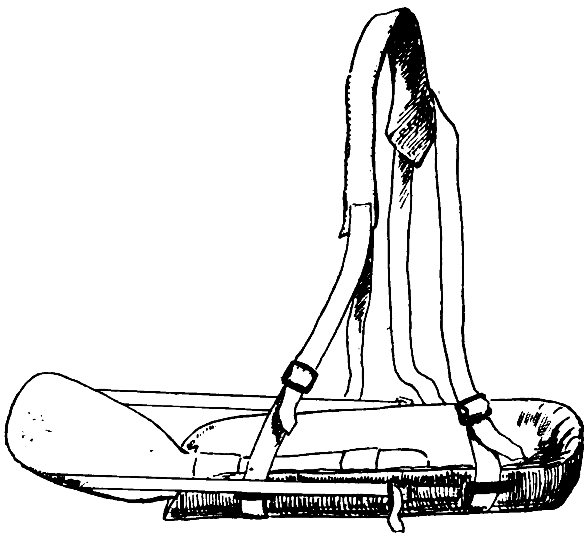


Fig. 276.—Arm-sling with yoke.
Made in papier-mâché and covered with khaki. The hand can be raised to angle required.

Fractured metacarpals or phalanges should have extension applied, the extension being taken and fastened over the end of the splint. Under no circumstances should a finger be amputated unless it is hopelessly destroyed.

As soon as the wound is sterile it is sutured, if this is possible. If impossible, the wound edges should be approximated in order to diminish the extent of exposed tissue, and what breach of the surface is left should be skin-grafted.

The fingers should never be allowed to become contracted, and this can always be avoided by means of a suitable splint.

Massage and exercises should be begun soon after the wound has healed, and the splint should be always replaced. Under no circumstances should the patient be allowed to sleep at night without his splint applied.

Later operations will probably be required in the form of tendon or nerve transplantation, and to facilitate the success of these subsequent operations it is of the highest importance to avoid fibrosis and matting of the tissues, which will always follow if sterilisation is delayed. It is essential to hand these patients over to the orthopædic surgeon in the best possible condition for subsequent operation—that is, it must be seen that

the wounded structures are not matted up in fibrous tissue. This can only be accomplished by rapid sterilisation and suture, followed by massage and exercises.

Gunshot Wounds of Superior and Inferior Maxillæ.

A series of fourteen cases of gunshot wounds involving the maxillæ contained six involving the mandible and eight the superior maxilla. The wounds on the whole were of an extensive nature, and in this series there was one death.

This class of wound may involve the soft tissues of the face, the tongue, the floor of the mouth, the pharynx, the hyoid bone, or the base of the skull.

In two of the cases tracheotomy was necessary, as œdema of the glottis had occurred, owing to infection of the pharyngeal wall and base of the tongue.

The immediate complications are—

(1) Falling back of the tongue occurring in association with fracture of the mandible. The patient on falling asleep, suddenly wakes up cyanosed and terror-stricken; consequently, his sleep is fitful and restless.
(2) Inability to swallow any form of nourishment. It is alarming how rapidly these patients lose weight during the first eight or ten days in hospital.
(3) Sepsis of a very offensive nature and showing a tendency to spread with great rapidity into the submucous tissues. This complication in injuries of the upper jaw involving the pharynx has caused a rapidly spreading œdema of the glottis, necessitating, as already stated, tracheotomy in two cases.
(4) The presence of foreign bodies in the substance of the tongue, causing acute swelling and œdema of this organ. We have in five cases extracted from the tongue pieces of the mandible and teeth.
(5) Acute spreading erysipelas, which has been an ever-present danger in all wounds involving the face.
(6) Septic pneumonia.

A remote complication to guard against is a neurasthenic and despondent state which is very apt to occur, and when once established is most difficult of treatment. These patients refuse to eat, will not speak unless spoken to, and rapidly go downhill. The danger is best overcome by nursing them in a convalescent ward with wounded men who are waiting to go to England, by encouraging them to roll bandages or run errands, or to do anything which will keep them employed. These men should never be allowed the use of a looking-glass.

Treatment of the Immediate Complications.—This in great part should be carried out as soon as the wounded man reaches the casualty clearing station. It consists in thoroughly cleaning the wound in the soft parts, excising as little as possible, carefully paring the skin edges, and suturing both mucous membrane and skin, the former with catgut, the latter with silkworm gut. Special attention should be paid to the corners of the mouth and the lip margins. These must be securely and accurately sutured first, and finally the soft parts forming the cheek, chin, and floor of the mouth should be dealt with, small tubes being left in the most dependent parts. Frequent mouth-washes must be used, and a dressing of 10 per cent. ichthyol in glycerin may be used as a prophylactic against erysipelas. Should foreign bodies be present in the substance of the tongue, they must be extracted.

If cases are left unsutured until they reach the base hospital, they are by this time so extremely offensive and septic that immediate operation is out of the question, and we have been compelled to wait seven or eight days before any plastic operation could be undertaken. During this time the patient has gone downhill, and is at this stage in a far worse condition to stand an operation, which might have well been done at once at the casualty clearing station. We would therefore recommend immediate operation at the casualty clearing station, because the wounds heal in the great majority of cases, and much subsequent suffering is avoided.

Treatment at the base hospital has for the first seven or eight days been directed to sterilising the soft parts, and Carrel's method has given both rapid and excellent results. It is exceedingly difficult to feed these men, and in some cases rectal feeding must be resorted to. During the period of sterilisation the mouth and tongue require constant attention, and for these a hydrogen peroxide mouth-wash is recommended. Sleep has been a difficult problem during this period, as the patient constantly wakes with a start and finds he is choking. This has been to some extent overcome by threading a silkworm gut suture through the tongue and fastening a pair of Spencer Wells' forceps on the end of the suture. Another difficulty is that the patient's tongue and pharynx get very dry, and dirty-brown mucoid flakes become deposited there, needing constant removal. We have used borax and glycerin for cleaning and keeping these parts moist.

When once the wound is reasonably clean, and one may allow some latitude in the case of the mouth, suture is performed. In every case, with one exception, the wounds healed well. Approximation and fixation of the fragments is an important point to consider at this juncture, and every operation has been carried out with the co-operation of the dental surgeon, who has at the time taken a cast and made a dental splint. If there has been no great breach of continuity in the body of the mandible, much can be done by the surgeon towards manipulating the fragments into position before suturing the soft parts. Providing the sutures hold,

and in every case but one they have, then the surrounding soft parts form an excellent accessory splint for the broken mandible. A temporary external splint is fixed over all and careful attention to the mouth and dressing twice daily of the wound with 10 per cent. ichthyol in glycerin form the immediate after-treatment. The patients are allowed up the day after operation. The way in which they make good loss of weight and the ease with which they sleep after the suture has been performed is surprising. Some cases were able to eat eggs, fish, minced chicken and bread-and-butter, a fortnight after suture.

It is important to see that there is no tension on the sutures approximating the soft parts. It is preferable to perform some flap operation rather than to trust to tension when approximating prepared surfaces, for sutured wounds of the face in which tension has been used will often break down. The patients will always try to talk or to convey their thoughts by expression, all of which will put further tension on the sutures. Lastly, the lips and structures forming the buccal orifice should always be dealt with first, so as to insure a buccal orifice which will neither break down nor contract; consequently, in this region mucous membrane must be accurately approximated to mucous membrane, and the line of the lip accurately maintained. If a portion of the lip be missing, then a plastic operation should be undertaken to replace it.

Deficiencies in the teeth can be undertaken when the soft parts have become healed and consolidated, and the dental splint must be applied at the earliest possible moment.

CHAPTER XIX

INJURIES OF THE HEAD

Frequency of Head Wounds.

BEFORE the introduction of the steel helmet, gunshot injuries of the head were of frequent occurrence, and formed a considerable percentage of any sum total of wounds.

Human curiosity, which knows no limits, has, through a peep over the parapet, often cost a man his life. Nor is the trench periscope without dangers, for it has happened on several occasions that a bullet turned in its course by this instrument has entered a soldier's head and caused a fatal wound.

Trenches are not necessarily safe cover from ricochet bullets, and these missiles have been the cause of fatal head wounds.

Soldiers, while taking aim over the parapet, or through holes in the parapet, are very apt to get hit in the head with a sniper's bullet. A common type of wound in this connection is that caused by a bullet, which, after striking the rifle-barrel, passes on into the soldier's head.

Frequently on a cold night, in order to prevent a water-cooled gun from freezing, both friend and foe would empty a portion of a belt of cartridges into their opponent's parapet. Head injuries at night from this cause alone were by no means infrequent.

Shrapnel or any other type of explosive bursting overhead is probably the commonest cause of head injury, and troops moving through a shrapnel barrage prior to the days of steel helmets would show a high percentage of head wounds amongst their casualties.

It is obvious, therefore, that in such circumstances the head is subject to injury almost more than any other part of the body.

Anomalies of Head Wounds.

Extensive head wounds involving brain and associated with immediate unconsciousness, if not at once fatal, are invariably so within an hour or two after infliction. Some may reach the casualty clearing station or a base hospital, but we can bear witness that these temporary survivors were but the few exceptions, for by far the majority die and are buried in the line.

On the other hand there are men suffering with penetrating head wounds who have walked a distance of a mile or more in order to reach an advanced dressing station. Some of these cases were heard of later in England doing well after operation at the clearing station or base hospital. Other cases almost identical as far as the wound was concerned immediately fell unconscious and either died or left the line in an unconscious condition. One case in particular that comes to mind is that of a sentry who was hit in the middle of the forehead, the bullet emerging in the middle of the vertex. One of us who was in the next traverse when it happened, and two other men present in the same traverse as the injured man, only discovered what had taken place when we spoke to him, and received no answer. Immediately after injury he was in the upright position, his head resting over his elbow on the parapet. Death in this case was instantaneous, and much blood was escaping from the superior longitudinal sinus.

Instances have occurred of men who, after receiving a penetrating wound of the head, have found their way to the regimental aid post, and while awaiting evacuation have slowly become unconscious. Again, it has frequently happened that a man hit in the head may talk sensibly and recognise his comrades for so short an interval as fifteen to thirty seconds before lapsing into unconsciousness. Some cases of perforating skull wounds with brain and blood exuding from the wound of exit have left the battlefield in a conscious state, whilst others have been profoundly unconscious from the start. This conscious state has been associated with certain definite planes of the head through which the missile has travelled, and these will be referred to later.

Certain Points in regard to Extensive and Fatal Head Wounds.

It is difficult to explain the length of time (sometimes two to three hours) that some men, though quite unconscious, survive the infliction of the most ghastly head wounds. Two cases are quoted to illustrate this.

(*A*) One man was hit in the head, while in trenches, by a bullet which had ricocheted off the sandbags. The ricochet bullet had carried away part of the calvarium and a very large part of the cerebral hemispheres. What brain remained appeared pulped and useless. Though quite unconscious, this man lived for an hour and three-quarters, and during this period the breathing was regular, as also was the pulse, the rate being 100 per minute. A quarter of an hour before death cyanosis appeared, with the familiar rattle in the throat. The pulse-rate at this period became more rapid, and at the end the heart continued to beat for three minutes after respiration had ceased. The limbs were flaccid throughout, the knee-jerks were present, but not exaggerated, and the leg was moved when the skin on the inner side of the thigh was pinched. The plantar response was not tested. The pupils were equal, widely dilated, and inactive to light, but the corneal reflex was present.

(*B*) Another man hit in the head with a ricochet bullet, causing an almost similar wound, though with not quite so much loss of brain substance, lived for two hours and a half. His symptoms were almost identical with the above, the heart continuing to beat for two and a half minutes after respiration had ceased. During the half-hour preceding death the breathing showed very irregular phases of apnœa and dyspnœa, though the respirations by no means conformed to a true Cheyne-Stokes type. The knee-jerks were present but not exaggerated; there was no plantar response and no ankle clonus. The pupils were equal, widely dilated, and inactive to light, though the corneal reflex was present.

The remaining cases differed but little from the above so far as could be ascertained from a rapid and somewhat rough examination. The following symptoms were more or less common to all:

(1) Regular pulse-rate varying from 100 to 120, accelerating before death.
(2) Persistence of the heart's action after respiration had ceased.
(3) Dilated or unequal pupils, inactive to light. Corneal reflex present.
(4) Conjugate deviation of the eyes in three cases.
(5) Presence of knee-jerks, which were not unduly brisk.
(6) Absence of plantar response and ankle clonus in the cases tested.
(7) Cutaneous reflex present in the thigh.
(8) Absence of convulsions.
(9) Absence of vomiting, but fæces and urine were voided.

An explanation of the persistence of vital functions in cases so appalling is perhaps to be found in an intact condition of the medulla, pons, and perhaps the subthalamic region. This is but a suggestion, for no post-mortems were possible under existing circumstances. These gruesome cases are nevertheless interesting in that they furnish proof of respiration and heart's action continuing in man independently of the cerebral cortex, and they further go to prove not only the automatism of these two vital functions, but also that one can exist independently of the other. The condition of the reflexes is also of interest.

Nature of Head Injuries.

A wound of the head may involve—

(1) Scalp.
(2) Skull.
(3) Brain.

(1) Scalp Injuries.—Scalp wounds are of the contused, incised, or lacerated variety.

CONTUSED WOUNDS vary from a bruise of the scalp to the formation

of a subepicranial hæmatoma, and may be associated with cerebral concussion or even cerebral laceration. On more than one occasion a contused wound of the scalp has been complicated by a fracture of the bony cranium, especially the basis cranii. Unconsciousness may or may not be present, but it is this type of wound that not infrequently occasions hæmorrhage from the middle meningeal artery, and this must always be borne in mind. Contused wounds of the scalp usually result from being buried in a dugout, by the parapet, or through being in the neighbourhood of an exploding Minenwürfer.

Incised Wounds of the scalp are usually the result of missiles, blunt instruments such as the butt end of a rifle, bayonets, knives, or other weapons used in hand-to-hand fighting. These wounds vary both in length and depth from little more than an abrasion to extensive incisions involving all structures down to bone. As a rule they are of a fairly clean nature, and heal rapidly after excision and suture. They may or may not be associated with cerebral concussion or cerebral hæmorrhage, and not infrequently they are complicated by fracture of the skull.

Lacerated Wounds are the result of missiles or heavy hand weapons, such as a weighted entrenching-tool handle or the butt end of a rifle. These wounds are most often extensive and dirty, and in some cases the scalp has in great part been torn back, remaining attached by a broad pedicle. Rarely is the vitality of such lacerated scalp destroyed, and excellent results have followed its cleansing, followed by immediate suture. We cannot recall a case in which we saw gangrene of the scalp. Lacerated scalp wounds may also be complicated by concussion, cerebral hæmorrhage, or cerebral laceration, and not infrequently by fracture of the basis cranii.

(2) **Wounds of the Skull.**—These are of almost every variety, but the following are the more common :

(1) An intact outer table with a fracture of the inner table.
(2) Fissured fractures.
(3) Gutter fractures.
(4) Depressed fractures.
(5) Penetration of both inner and outer tables.
(6) Complete removal of bone.

A missile impinging on a spheroidal surface, unless it hits that surface perpendicularly, tends to glance off and take a tangential course. This is what happens in the case of the skull. When the blow is perpendicular to the surface at the point of impact the outer table is first fractured, but before fracture results the skull, by virtue of its elasticity, in younger people tends to give. In the case of the outer table, where the radius of curvature at the point struck is greater than that of the inner table, nothing further may happen as far as the outer table is concerned. This is not always the case for the concentric inner table, whose radius of curvature at the point struck is less than that of the outer. Consequently, the inner table may

give at a time when the outer table holds, and this is what actually happens in a number of cases.

If, however, the outer table is fractured by a perpendicular hit, the inner table has now to bear the force of impact not only of the missile, but also of the fractured piece of the outer table that it carries in front of it. This results, not in a simple perforation of the inner table, but in splintering, often of an excessive degree. Thus, in most cases of fractured wounds of the skull the damage inflicted on the outer table is little indication of that sustained by the inner table, and this is a truth that should never be forgotten.

Intact Outer Table with a Fracture of the Inner Table.—As mentioned above, this is not an uncommon occurrence, and the damage to the inner table is apt to be overlooked, as many of these cases are not associated with symptoms. One instance will suffice to show this. Sergeant ——, hit in November, 1915, sustained a scalp wound, which was of the furrowed variety and ran horizontally for a distance of 3½ inches above the right ear. The skull was exposed, and one of us who saw him directly after the injury was satisfied that there was no visible fracture of the skull. He was perfectly well, and after his wound was dressed he walked to the advanced dressing station, one mile distant. He was evacuated to England, and returned to home duty one month later. In April, 1916, he rejoined his unit in France, and on the night of his return he was seen by one of us in a typical Jacksonian fit. He was again evacuated to the base, where an operation was performed. An old fracture of the inner table was discovered, with callus formation, and this was removed. The operation proved a complete cure up to the present, as we were able to ascertain his history a year later. This N.C.O. never had a symptom, not even headache, between November, 1915, and April, 1916.

Fissured Fractures are seen most frequently in the calvarium and the basis cranii. They may involve the outer table only, but more often both tables are damaged. They are the result of either a glancing blow by a missile, or a blow on the head with a heavy instrument. The skull yields to a certain point only when struck with a heavy weapon, and when the bursting point is reached it gives, a fissured fracture resulting. Fissured fractures are not uncommonly associated with large lacerated scalp wounds. They may either be symptomless or, on the other hand, rapidly fatal. When a fissured fracture involves the calvarium, a degree of splintering of the inner table may be present.

Gutter Fractures.—Gutter fractures are caused by pieces of high explosive, sabres, and sometimes rifle bullets. The outer table is depressed and the inner table extensively involved. This type of fracture is perhaps the least fatal of all. Men with gutter fractures apparently situated over the Rolandic area have walked from the line to the advanced dressing station, and have shown no symptoms at all.

One interesting case from a few similar may be quoted :

Pte. —— sustained a gutter fracture just in front of his right parietal eminence in December, 1915. He walked unaided to the regimental aid post, and from there to the advanced dressing station. He had neither headache nor symptoms of concussion. When he reached the clearing station he had complete loss of power in the left leg. He was trephined at this latter unit, and was evacuated to the base ten days later. The last we heard of him was that his leg had completely recovered soon after arrival at the base ; the wound in the scalp had healed, and he was marked to go to England.

Depressed Fractures are perhaps the commonest of skull injuries. They are the result of a hit with high explosive, shrapnel, or rifle bullets, although they may be produced by a blow over the head with a weighted stick or the butt end of a rifle. The amount of damage to bone is variable, but the inner table is, as a rule, severely comminuted. Depressed fractures are usually associated with varying degrees of concussion, and frequently with focal symptoms.

Penetration of Outer and Inner Tables.—This is a very common form of injury, and the result of hits by small pieces of high explosive, shrapnel balls, or rifle bullets. Penetration or perforation of the bony cranium may occur, but the damage to bone is invariably the same. The outer table at the wound of entry usually presents a small hole, but the inner table is comminuted. After entering the skull, the missile may come to rest in the brain substance. If this does not happen, the missile continues its course and emerges from the skull, leaving a large comminuted wound of exit from which blood and brain-matter escape. If these latter in-and-out wounds be associated with immediate unconsciousness, they are invariably fatal. A number of unconscious men with brain protruding left the line, but in every case—and we kept careful notes—the regiment was within a very few days informed of their death, which had usually occurred at the casualty clearing station. It may be taken as a fairly sure guide that if one of these injuries be associated with unconsciousness and a pulse of over 100, then the case is hopeless. Some surgeons can doubtless report recoveries, but recovery is very much the exception.

Perforating wounds of the skull may, on the other hand, be associated with consciousness, and though brain be protruding from the wound of exit, a number of such cases have recovered. Some of these men, though conscious at first, may during or after a motor journey to the clearing station become unconscious, yet after operation consciousness has returned and recovery has followed. Thus it is exceedingly important for the surgeon at the clearing station to know *whether or not an interval of consciousness, however short, did exist after the injury, and a short note by the regimental medical officer to this effect on the tally is of the greatest possible assistance and importance.*

Complete Removal of Bone.—Such an injury is almost invariably due to a glancing blow with a piece of shell, though more extensive damage

of this kind has occurred as the result of the rending force produced by the explosion of a high-explosive shell.

The following are instances:

Pte. —— was struck on the head in April, 1917, by a piece of high explosive, in the region of the right parietal eminence. The missile turned down a flap of his scalp and carried away a piece of the skull about the size of a five-shilling piece. The membranes were untouched. He suffered from headache and nightmare, both of which symptoms dis-

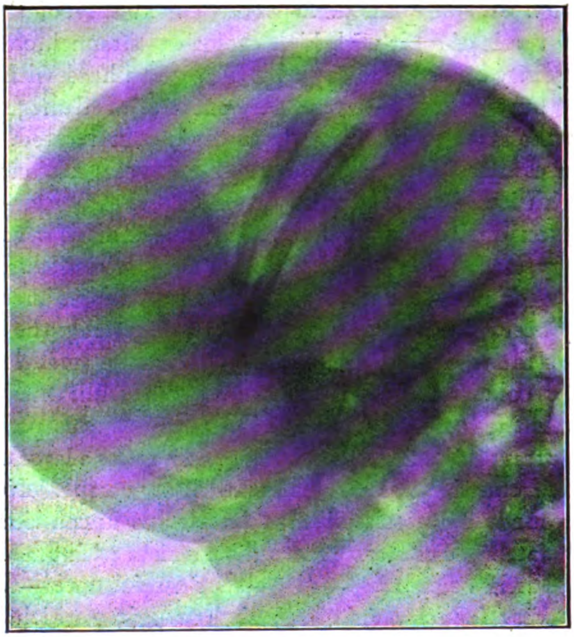


FIG. 277.—Piece of skull carried away by missile, which in this case was high explosive.

The dura was intact. The symptoms were headache and nightmare, which completely disappeared after suture of the scalp.

appeared entirely after the flaps of scalp had been sutured back into position.

Gnr. —— was sleeping in a ground bivouac one Sunday afternoon in May, 1915. The enemy suddenly sent a few salvos of high explosive into the camp, one shell striking the ground and exploding 10 yards from his bivouac. He was seen five minutes after the shell had exploded by one of us. The top of his skull had been removed almost as cleanly as at a post-mortem, the membranes being quite intact. Though quite unconscious, he lived for fifteen minutes.

When pieces of skull have been completely carried away by the missile, the meninges are generally involved. Quite a number of cases have

occurred, however, in which the meninges have escaped, and two of the most constant symptoms of this latter condition, so long as the dura mater is left uncovered by the scalp, have been *headache and nightmare*.

(3) **Wounds of the Meninges and Brain.**—It is rare to find injury of the meninges existing apart from injury to brain, but injury of the brain may exist apart from injury to the meninges.

FIG. 278.—Same patient as Fig. 277 after suture and healing of scalp. Recovery was complete.

Wounds of the meninges and brain are the result of—

(1) An injury to the head not necessarily involving the skull, but contusing the scalp.
(2) An injury which opens the scalp, but causes no damage to the outer table of the skull.
(3) An injury which fractures both tables of the skull.
(4) Penetrating and perforating wounds of the skull.

Condition (1) may be complicated by cerebral laceration, extradural or intradural hæmorrhage, separately or in combination, or by severe cerebral concussion. Cerebral laceration may occur either in that part of the brain situated immediately below the point of impact on the skull, or at a point on the opposite side of the brain (the *contre-coup* effect). The extent of the laceration is variable, depending upon the force spent in producing it.

Extradural and intradural hæmorrhage are not at all uncommon accompaniments of head injuries which do not involve the scalp or skull. Extradural hæmorrhage is most often the result of rupture of the middle meningeal artery or one of its branches, whereas intradural hæmorrhage originates from ruptured vessels (usually veins) in the pia mater.

The following case may be quoted as an instance of meningeal hæmorrhage where both scalp and skull were intact :

Cpl. N——, R.F.A., was on September 24, 1917, picked up unconscious. Examination showed that his tongue was not bitten. The next day two fits were reported ; he regained consciousness, but could

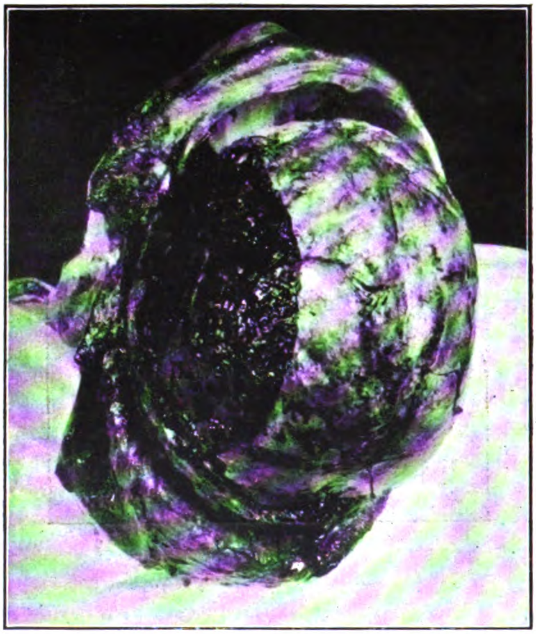


FIG. 279.—Severe hæmorrhage from middle meningeal artery, the result of a contused wound of the head.

Note the compression of the right cerebral hemisphere.

remember nothing, and could not read simple words. On September 29 he was still dazed, his memory for past events was nil, his speech was slow, and he took a long time to answer questions.

On the left parietal area was a painful swelling due to contusion of the scalp. Pupils equal, but sluggish to light, especially on the right side. The tongue was protruded to the right, but the cranial nerves were otherwise normal.

On October 1 there was contraction of the right visual field, the left being quite normal. Blunting to pin-prick sense was present over the right side of the face. The deep reflexes were brisk, and the plantar

response was flexor. Muscular power of the right side feebler than the left.

Later in the day complete anæsthesia and analgesia were present over

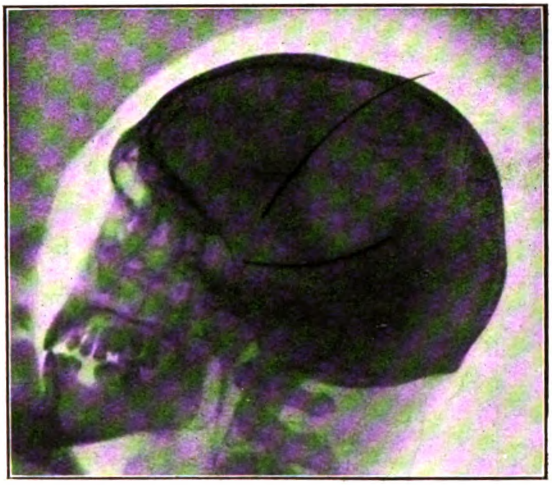


FIG. 280.—Corporal N——. X-ray showing the trephine hole in the skull. Wires have been laid over the surface markings of the fissure of Rolando and the fissure of Sylvius.

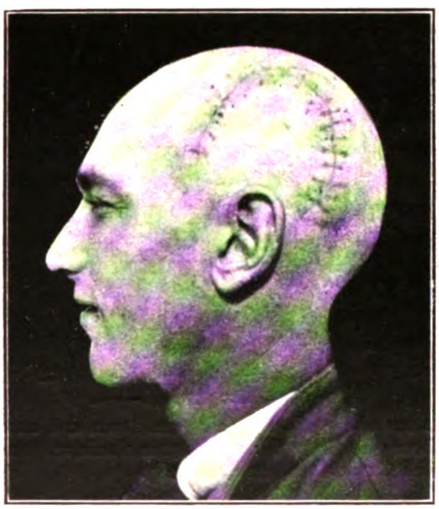


FIG. 281.—Corporal N——. Photograph shows the trephine incision healed.

the right half of the body. This was associated with muscular twitchings in the right arm and complete loss of power on the right side. Finger-thumb reflex absent on the right side. Joint sense in right upper and lower limb was absent, and astereognosis was well established.

Lumbar puncture showed cerebro-spinal fluid to be under increased tension, but examination of the fluid was negative.

On October 2 an operation was performed and the skull trephined just in front of the left parietal eminence. The hole in the skull was enlarged, and no pulsation of the dura was observed. On opening the dura, a large

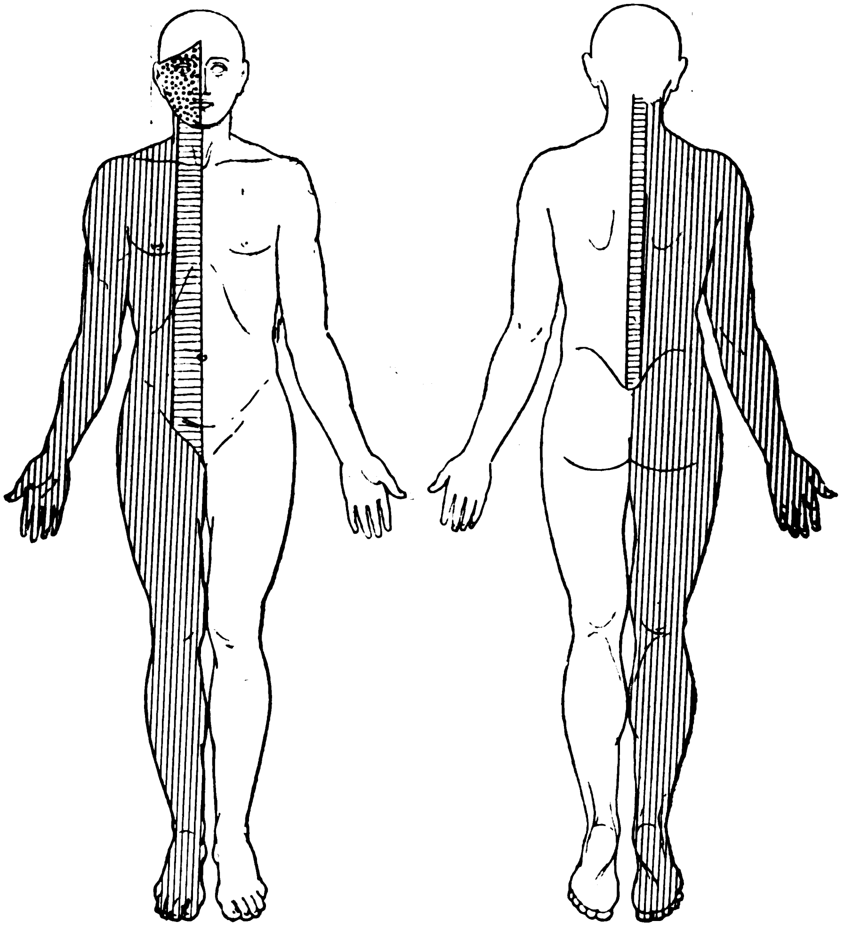


FIG. 282.—Corporal N——.

Vertically shaded areas are those of complete anæsthesia and analgesia. Horizontally shaded areas are those of slightly diminished anæsthesia and analgesia. Dotted area that of very diminished anæsthesia and analgesia.

localised blood-clot was evacuated from the precentral and postcentral areas, and a bleeding vessel in the pia underrun and ligatured.

The patient made an uninterrupted recovery, and on October 12 sensation had returned, but paraphasia was present. He left for hospital ship a month later, able to walk and look after himself, and completely normal.

Severe cerebral concussion, if present, differs in no way from that seen

in civilian practice. Cases should be carefully watched, as this condition is not infrequently found to be complicated with hæmorrhage.

Condition (2), in which the scalp is laid open, but the outer table of the skull remains intact, is one of the most deceptive of head injuries. A case of this type may show either cerebral symptoms or no symptoms at all, and this despite the fact that the inner table has been fractured and the dura injured.

Later, however, after intervals of three months or more, symptoms of cerebral irritation develop, and damage hitherto latent now becomes manifest.

Fig. 283.—Corporal N——. Shows complete recovery.

Thus callus-formation may have occurred to a sufficient degree to cause pressure on the motor centres, and typical Jacksonian epilepsy results, as was shown in a case mentioned earlier in the chapter.

If the meninges are involved, then adhesions may form between them and the cerebral cortex, and these, after organisation, may be the cause of cerebral irritation.

It may happen, however, that the inner table may escape injury altogether, but extradural or intradural hæmorrhage may occur, as exhibited in the above case of Cpl. N——.

Again, the damage to the inner table may be so extensive that not only are the meninges ruptured, but fragments of the inner table are driven into the brain substance.

Where the force of the missile has been sufficient to fracture both the inner and the outer table, the damage sustained by the inner table is excessive, and the meninges are usually torn. Fragments of bone are driven into the cerebral cortex, which is lacerated to a degree comparable with the amount of bone carried in and the force of the blow. Symptoms will result compatible with the amount of damage done and the area of the brain involved. Cases do occur, however, in which the meninges are intact, but trephining shows blood beneath the dura mater and absence of cerebral pulsation—in other words, there is abnormal intradural tension, the result of hæmorrhage and traumatic cerebral œdema.

Damaged brain, like other tissues, becomes temporarily œdematous, the œdema lasting from a week to a fortnight. Œdema by itself will produce intracranial tension, with either focal symptoms or symptoms of general compression.

Penetrating Wounds of the skull form a very common class of head injury, the missile most often being some type of high explosive. Rifle and machine-gun bullets have not frequently been seen lodged in the brain, but shrapnel balls are not very uncommon, though far less frequent than pieces of high explosive.

A missile penetrating the brain carries before it bone (rarely scalp), hair, and perhaps a piece of the soldier's cap, though the latter is not a common event since the introduction of the steel helmet. The track of the missile through the brain is ragged and usually filled with blood-clot. There is a disruptive effect, which results in a localised cerebral œdema both around the track and around the missile. The perforation of the meninges varies in size according to the size of the missile and its velocity, the latter governing the nature and amount of bone damage. The cerebral œdema and hæmorrhage produced by the passage of the missile into the brain give rise to a varying degree of intracranial tension from which either local or general symptoms result.

If in its course the missile strikes and ruptures a large artery, fatal hæmorrhage may result, the patient dying from a rapidly induced cerebral compression.

The skull may be penetrated at any point; thus, the missile may enter anywhere in the calvarium, or may traverse the face. Cases are common in which the missile has entered the skull through the orbit, at the same time disorganising the eye. Less frequently has it entered through the nares or mouth. The forehead is a common site of entry, and in this connection the frontal sinuses have often been involved. We have been concerned in a number of cases where both walls of the frontal sinus have been penetrated, the missile coming to rest in the corresponding or opposite cerebral hemisphere.

Two cases were admitted to hospital in which the missile had entered the external auditory meatus, coming to rest in the cerebral cortex of the opposite side.

Perforating Wounds of the skull are associated with a greater destruction to brain than are penetrating wounds. This is no doubt due to the greater velocity of the missile and the consequently more extensive damage to bone. The wound of entry may be at any point in the scalp or the upper face, the exit wound depending on the course taken by the missile.

From the exit wound blood and brain are usually exuding. In a number of cases the missile has traversed the skull, but has not emerged from the scalp. It can readily be felt beneath the scalp, and with it is associated extensive comminution of both outer and inner tables.

Perforating wounds may involve both cerebral hemispheres, but there are a considerable number which do not. The whole question depends on the direction of the missile in regard to the position of the soldier's head. Thus, a man may be hit in the right forehead, and the missile emerge from his right parietal, temporal, or occipital areas, or from similar areas on the opposite side. Again, he may be hit in the temporal region, and the missile, after a very short intracranial course, emerge 2 or 3 inches farther back on the same side. This latter type of wound was of constant occurrence in the line.

Consciousness may or may not be lost, but in the case of immediate unconsciousness caused by a perforating wound of the skull we have never known a single recovery. We saw many of these cases in the line, and can bear witness that most of them died either instantaneously or before they could be evacuated, whilst in the case of the few who were evacuated the regiment was informed, without exception, of their death.

The cause of death in cases that fall unconscious is no doubt attributable to hæmorrhage and excessive destruction of brain substance.

Still, it is surprising that numbers do recover where a large amount of brain substance has been destroyed *in certain regions*, and this information alone is most valuable to the surgeon who undertakes cerebral work, either in civilian or military practice.

Post-Mortem Findings.—Post-mortem examinations on fatal cases of head injury have revealed much interesting and valuable information. Deaths have occurred in all grades of head injury, and in the slighter cases the fatal issue has been the result of other serious wounds complicating. It will be convenient to consider first the post-mortem findings in cases of injury in which the skull is not fractured.

The most constant findings are either hæmorrhage or cerebral laceration. The dura is usually intact, and the hæmorrhage is either extradural or intradural.

If extradural, the damaged vessel is either the middle meningeal artery or one of its branches, whereas intradural hæmorrhage has most often resulted from ruptured veins in the pia mater. Brain laceration in these slighter cases is small in amount, ranging from slight bruising and œdema to an irregular tear of one or more convolutions.

Cases have come to autopsy where, in addition to the cause of death,

there has been present a scalp wound of small extent, and not complained of during life. Removal of the skull-cap has shown the presence of a very small hæmorrhage beneath the dura, though the skull itself has not been fractured.

Extradural hæmorrhage is either limited or excessive, localised or diffuse. Thus, in the case of a Greek who died half an hour after admission to hospital and one hour after injury, the greater part of one side of the dura was separated from the skull and the space between dura and skull was occupied by an extensive blood-clot. In this case part of the posterior middle meningeal artery lay within a bony canal, and at its point of emergence it had been ruptured. Should the bleeding from the injured vessel be slow—and such may happen where a smaller meningeal branch is involved—then the hæmorrhage is most likely to be limited and localised.

When hæmorrhage is subdural, it has invariably occurred from ruptured veins in the pia mater. Hæmorrhage of this kind is either diffuse or localised. Some cases in which symptoms before death were those of general cerebral irritation, have shown a thin diffuse hæmorrhage almost completely covering the hemisphere, whereas others have shown a thin clot, the dimensions of which have been limited by the formation of sub-arachnoid adhesions, and the latter cases are those in which hæmorrhage from the injured vessel has taken place slowly and gradually.

When fracture of the skull has occurred, the dura has invariably been torn, except in cases of fracture of the basis cranii and some fissured fractures of the vault.

The post-mortem appearances of a fractured basis cranii differ in no respect from those seen in civilian practice, and the fracture may traverse either the anterior, middle, or posterior fossa. In all cases of penetration and depressed fracture the inner table is much more comminuted than the outer, and ragged pieces of the former have invariably entered the cerebral cortex, causing variable degrees of cerebral laceration. Both extradural and intradural hæmorrhage have usually occurred, the former being of limited and small extent.

Cases in which the missile has lodged in the brain show fairly constant post-mortem findings. The track of the missile in the brain is filled with blood-clot containing one or more pieces of bone, usually derived from the inner table. At the end of the track is the missile, with, perhaps, a piece of cloth and some hair, though since the steel helmet has been worn and the hair cut short the latter accompaniments are rare. Around the missile is a cul-de-sac in the brain substance, which is also filled with blood-clot. The walls of the track are ragged, and into their substance small hæmorrhages have occurred. The track walls and the brain substance in their immediate neighbourhood are soft and œdematous. If the ventricles have been involved, their cavities have been found to be full of blood-clot.

If the missile has perforated the skull, then the damage to brain sub-

stance, though of the same quality as that seen in penetrating wounds, is, as already stated, more extensive.

Should meningitis be the cause of death, the post-mortem appearances differ in no way from those of an ordinary acute meningitis seen in civilian practice. The subarachnoid space contains pus, scattered regularly or irregularly over the surface of the hemisphere or hemispheres, the vessels of the pia are congested, and the basal cisterns are full of a purulent or semi-purulent fluid.

Complications of Head Injuries.

Infection.

Speaking in a broad sense, every wound of the brain is infected, but this war has taught us the important truth that the brain and its meninges, if put under suitable conditions, are both able to withstand and successfully combat infections of the most virulent kind.

Wounds of the brain form ideal conditions for anaerobic infection, for there is blood-clot within a space that soon becomes shut off from the exterior.

The subarachnoid space, being nothing more than a large bursal sac, probably possesses powers of resisting infection similar to those of the peritoneum.

As soon as the subarachnoid space has been traversed, the perforation helps to form part of the septic track of the missile. Adhesions, however, are soon thrown out which glue the wounded edges of the arachnoid, pia, and dura together, so that the subarachnoid space becomes early shut off.

The clot filling up the track in the brain is, however, a dangerously close neighbour to the septic wound in the scalp and skull, and at the bottom of the track, embedded in clot, is the missile, unless the wound be perforating.

The organisms entering the brain are those met with in other wounds and described in previous chapters.

Gas-formation in the clot has been present in several instances, and the *B. perfringens* has been isolated. Gas exuding from the brain has a peculiarly offensive and pungent odour, and differs from the smell of gas in other wounds of the body. Patients have been admitted to hospital with this condition who were perfectly conscious, and have shown no other symptoms, except, perhaps, a monoplegia or slight headache.

We are quite at a loss to explain why it is that patients suffering from gas infection are for as long as four days after injury and before operation apparently well ; they eat, sleep, read, and smoke, they do not often suffer from headache, and the most constant symptoms they have shown have been purely focal in type. There is no doubt whatever that the cortex possesses very high powers of immunity, never known to us before this war, against infection of the most virulent type. Cases of acute encephalitis have occurred, but in our experience, out of a large number

of cases of penetrating head injury seen from start to finish, they are the rare exceptions.

The whole danger seems to lie in infection of the meninges, and if while operating the newly formed subarachnoid adhesions are inadvertently broken down, then a serious risk of meningitis follows.

Spreading infection in the damaged skull-bones or scalp is a phenomenon practically unknown to us.

Cerebral Venous Sinuses.—Infection may spread to the large cerebral venous sinuses, and thrombosis of these vessels is the result. It is rare to find infection of the sinuses following injury of brain substance, it usually follows an infected wound of the sinus itself. Such a complication is extremely grave, and we have seen no patients recover.

One case of thrombosis of the superior longitudinal sinus resulting from a wound examined post-mortem by us showed a partially disintegrated clot which contained gas and had spread backwards into one of the lateral sinuses and reached the jugular vein on the same side. A large abscess was found in the right lung, and several small abscesses in the left lung.

Another case of thrombosis of the cavernous sinuses showed bilateral exophthalmos before death. Post-mortem examination showed a localised abscess in the right pleura and multiple abscesses in both lungs. The patient died of septic pneumonia.

It would seem that infection of the sinuses by organisms associated with war wounds gives rise to a thrombus, which readily breaks down and becomes disseminated as emboli.

One case of thrombosis of the lateral sinus before death showed an acute arthritis (probably embolic) of the right knee-joint. This case died before the knee-joint condition matured.

Hernia Cerebri is undoubtedly associated with a subacute type of infection. From the wound in the dura a mass of brain herniates, which slowly gets bigger, and is often later associated with a discharge of cerebro-spinal fluid. Earlier in the war this unfortunate complication was common, but to-day, thanks to a more perfect technique and thorough understanding of cerebral injuries, so admirably brought forward by Colonel Percy Sargent and Colonel Cuthbert Wallace, this complication is a rare event.

Intracranial Aneurysm.

This is a rare complication, and we have been concerned in the treatment of only two cases. Both were associated with complete blindness, and in both the aneurysm occurred between the intracranial portion of the internal carotid artery and the cavernous sinus. Both cases also showed a bilateral pulsating exophthalmos which underwent spontaneous cure without operation.

Symptoms.

Immediate symptoms vary from unconsciousness to no symptoms at all. If a man falls unconscious after receiving his wound, he may either show a slow pulse, slow, shallow and sighing respirations, with pupils

semi-dilated and inactive or sluggish to light, and it may be possible to rouse him to some extent by shouting in his ear; or, on the other hand, he may be profoundly unconscious, with unequal and inactive pupils and breathing stertorous. The pulse-rate in the latter case may be either slow or as high as 110 or 120 beats per minute. Reflexes will vary in these unconscious men. Seen soon after injury, the deep reflexes have been most variable and the plantar response indefinite. It seems that the reflexes do not immediately after injury conform to what is commonly taught, but some time must elapse before they can be looked upon as reliable guides. Flaccidity of the limbs is present in all men who fall unconscious, and persists for a few hours. Hence in very early cases—that is to say, in men seen immediately after they fall—the respiration, pulse and pupils are the important points to note. Should hæmorrhage from the nose, mouth, or ears be present with stertorous breathing and unconsciousness, the symptoms are clearly those of a fractured basis cranii.

Aphasia and loss of memory are not uncommon symptoms of head injury, and may be the result of either concussion, shell-shock, or more definite organic damage to the cortex in the region of Broca's area or the frontal lobes.

Hemianopsia, contraction of the fields of vision, or paracentral scotoma, are associated with injury of the occipital lobes.

Loss of joint sense and the presence of astereognosis point to lesions in the post-Rolandic area. Lesions of the precentral or postcentral gyri are associated with motor or sensory changes, and most common, if not the most interesting, are the monoplegias. Associated with Rolandic lesions is the loss of the finger-thumb reflex. This reflex is obtained by flexing the little and ring fingers acutely on the palm at the metacarpo-phalangeal joint. In a normal individual when this is done the thumb becomes hyper-extended and adducted. Should a lesion of the Rolandic area be present, this reflex will often fail (see Fig. 284).

Lesions of the Rolandic area may give rise to symptoms of monoplegia or hemiplegia, or these same symptoms may be caused by a localised hæmorrhage of the cerebral cortex. Twitchings or fits are indications of cerebral irritation, and are more often attributable to hæmorrhage than to actual damage of brain substance.

Wounds of the brain that are from the start symptomless are associated with damage of the silent areas.

Later—that is to say, four or five hours after injury—the altered reflexes become established. In true organic lesions of the motor cortex or the corona radiata the deep reflexes are increased, and with this there is often spasticity of the affected limbs. The knee-jerks, Achilles jerks, and supinator jerks, become exaggerated, especially on the opposite side, and there may be ankle-clonus with a one-sided extensor plantar response.

Motor power in the muscles of the affected limb, as shown by the grips and movements, may be either very diminished or completely absent.

Sensory changes may or may not be present, depending upon whether the postcentral gyrus or its tracts have or have not been injured.

Interference with speech and articulation, inequality of the pupils, and loss of memory, may all point to intracranial pressure or injury to Broca's area.

Protrusion of the tongue to one side, paralysis of the muscles of the eyeball, ptosis, complete facial palsy, deafness and blindness, are important

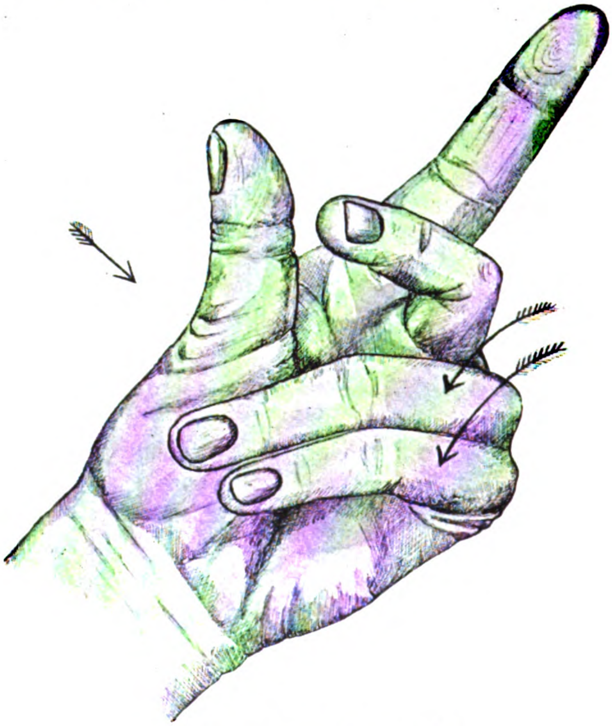


FIG. 284.—Finger-thumb reflex.

points to note in connection with injury of the cranial nerves. Incontinence has very rarely been an early symptom of cerebral injury, unless unconsciousness be present.

Later symptoms are those due to infection, organised injury of the meninges or brain, or callus-formation from an unrecognised fracture of the inner table.

The earliest symptoms of infection of the brain are headache and vomiting, and an early examination of the fundus oculi may show swelling of the disc with engorgement of the retinal veins. These symptoms are quickly followed by rigidity of the muscles of the back of the neck, the presence of Kernig's sign, squint, and unconsciousness, with incontinence of urine and fæces.

Infection may follow, and take the form of a localised encapsuled

abscess around a missile that has been left in the brain. This abscess may lie latent for as long as two years or more without giving rise to symptoms. A few such cases have been reported during the present war. An old injury of the membranes which has become organised and bound to the cortex by adhesions may, if the injury be in the neighbourhood of the Rolandic area, give rise to Jacksonian epilepsy, as may also an excess of callus which has formed around the site of a fracture of the inner table.

The symptoms of sinus thrombosis are headache, vomiting, and rigors, followed by the dissemination of emboli. Thrombosis of the superior longitudinal sinus may spread backwards to the lateral sinus of one side, and thence to the internal jugular vein. Later symptoms are those of pyæmia, metastases appearing first in the lungs. In one case of thrombosis of the cavernous sinuses there was bilateral exophthalmos.

Examination of a Case of Head Injury.—The regimental medical officer is the first man who can give important information in a case of head injury, and what he must note is whether or not the patient was conscious for any interval, however short, after being hit. He should also note the pulse, the respiration, the condition of the pupils, and the presence of hemiplegia or paraplegia. These few points only take but a minute or so to ascertain, and this small amount of information is invaluable to the surgeon who first deals with the case.

On admission to the casualty clearing station or base hospital, the first point to strike the surgeon is the presence or not of unconsciousness, and whether or not the patient can be roused by shouting into his ear. The respiration should be noted, as to whether it is stertorous or not, and the pulse-rate recorded, whether slow or rapid.

Any twitchings in the fingers or toes or any convulsion should be carefully observed, special note being made as to where the twitching commenced.

The wound is next examined, and its character, whether penetrating or perforating, ascertained. The presence of any brain exuding from the wound of exit should be looked for. If the surgeon has the information from the regimental medical officer that a man was conscious after receiving his wound, though he may now be profoundly unconscious, with a rapid pulse, it should not deter him from operating.

If the patient is conscious his speech and articulation are noted, and also the condition of the pupils, whether equal, dilated, contracted, or active to light. The fields of vision should at the same time be roughly tested and any gross contraction looked for.

The condition of the remaining cranial nerves is rapidly ascertained by asking the patient to protrude his tongue, show his teeth, move his eyes, close his eyes, and by testing his hearing.

Monoplegia, hemiplegia, or anæsthesia, are next looked for and noted, and the reflexes tested. Spasticity may be present. The reflexes to note are the knee-jerk, the Achilles jerk, the supinator jerk, the abdominal reflex, the finger-thumb reflex, and the plantar response. The presence

or absence of ankle-clonus is important. Hæmorrhage from the nose or ears should always be looked for.

Finally, the presence or absence of astereognosis and joint sense is ascertained. When the above examination is complete, and it takes but a short time, the fissures of Sylvius and Rolando are marked out as follows :

Take a point 35 millimetres back along the zygoma from the fronto-malar suture, and from here take a point 12 millimetres perpendicularly upwards from the upper border of the zygoma ; this will give the Sylvian point. Next take a point just in front of and below the parietal eminence. A line joining these two points will give with tolerable accuracy the marking of the Sylvian fissure.

By the ordinary formula mark out the fissure of Rolando. Having got the surface-markings of both these fissures, lay a thin wire along each, fastening it in place with sticking plaster. An X-ray can now be taken laterally and anteroposteriorly. By this means the foreign body can be localised and its position determined, both in relation to the hole in the skull and to the Sylvian and Rolandic fissures.

Diagnosis.

A soldier who has sustained a head injury is either conscious, subconscious, or unconscious.

If there be no wound of the scalp and no fracture of the skull, an unconscious state is the result of—

(1) Cerebral concussion.
(2) Intracranial hæmorrhage, either extradural or intradural.
(3) Cerebral laceration.

(1) and (3) frequently coexist. The important points to observe in making a differential diagnosis are the condition of the pupils, the nature of the breathing, and the pulse. A slow, shallow, and sighing type of respiration, with equal pupils not unduly dilated or contracted, and a normal or slightly heightened or lowered pulse-rate, point strongly to a state of cerebral concussion. Both light and corneal reflex are usually present, but diminished if the case be one of cerebral concussion.

Should cerebral laceration complicate a state of concussion, the symptoms of concussion may be modified, for in addition there may be symptoms of a subdural hæmorrhage, varying in amount according to the extent of brain damage. Thus, superadded to symptoms of concussion there may be signs of cerebral irritation, shown by twitchings or even convulsions. For instance, in one case operated upon for twitchings of the right hand and forearm, the injury being on the right side, it was found that a subdural hæmorrhage had occurred as the result of a cerebral laceration on the left side (*contre-coup*), and this is usually what occurs.

Cerebral concussion associated with twitchings or other symptoms *on the same side of the body as the injury* point strongly to cerebral laceration being present.

Cerebral laceration may be present in the absence of severe concussion, and may involve the brain on the same side as the injury, or the effect may be *contre-coup*. Severe headache, loss of memory, dizziness, drowsiness, restriction of the fields of vision, or motor and sensory symptoms, are all strong evidence of laceration with a degree of subdural hæmorrhage.

Intracranial hæmorrhage may or may not accompany cerebral laceration, and may be extradural, intradural, or both. Unconsciousness is by no means an immediate sequel of the injury in these cases, and if the medical officer who first saw the case can certify that the wounded man was conscious for any interval of time, this is most valuable information. A state of unconsciousness, with inequality of the pupils and stertorous breathing, following an injury is almost pathognomonic of extradural hæmorrhage, the source most often being an injured middle meningeal artery or one of its branches. If the bleeding is slow, then the appearance of unconsciousness is delayed ; if rapid, then symptoms of compression come on almost immediately. The limb on the opposite side of the body to the hæmorrhage may either be flaccid or spastic, and experience goes to prove that the early reflexes are of little value.

One case particularly interesting is that of Pte. ——, hit by a glancing blow over his right temporal region in October, 1915. He walked to the regimental aid post, and for five minutes talked sensibly. At the end of this time he slowly lost consciousness, the pupils became unequal, the right being greater than the left, and his breathing became stertorous. Unfortunately, it was broad daylight, and he could not be moved. As unconsciousness became deeper and signs of compression more pronounced, one of us trephined him in a dug-out in the line. An extensive hæmorrhage had occurred. The clot was turned out and the bleeding vessel (a branch of the middle meningeal artery) was tied. He was kept in the line for twenty-four hours, and was later evacuated from a field ambulance, having recovered consciousness and done well up to then.

Subdural Hæmorrhage is usually associated with symptoms of cerebral irritability, the subconscious state being frequently present, more rarely unconsciousness. Muscular twitchings, headache, convulsions, violent acts, contraction of the fields of vision, and loss of memory, are symptoms associated with subdural hæmorrhage. Cases of subdural hæmorrhage associated with transient monoplegias or hemiplegias are not uncommon, for with the hæmorrhage is present a degree of cerebral œdema, the result of the injury. Subdural hæmorrhage has rarely been associated with symptoms of cerebral compression unless an extradural hæmorrhage coexisted.

Unconsciousness with an Open Wound of the Scalp and a Fractured Skull.—If there be an open wound of the scalp with fracture of the skull, not associated with penetration, then an unconscious condition may be the result of either concussion or compression, or both. The above remarks as to the differential diagnosis apply equally here.

When penetration of the skull has taken place and unconsciousness exists, the X-ray is of great value in determining what damage is likely to have occurred. An almost invariable rule in these cases is, and we have time after time confirmed it both at operation and at autopsy, that if after being hit an interval of consciousness exists, however short, the case is one of hæmorrhage; if, on the other hand, the soldier is unconscious from the start, with stertorous breathing and rapid pulse, then extensive damage to brain has occurred.

When the missile has penetrated or perforated the skull, an X-ray taken in two directions, with wires laid over the fissures of Rolando and Sylvius, will give with tolerable accuracy *the direction of the path of the missile and its depth in the brain*, and from these data considerable information is afforded of the damage done.

Perforating wounds of the skull with brain protruding from the wound of exit, and associated with immediate unconsciousness and rapid pulse, denote extensive damage to brain substance, and are invariably fatal.

The following table may be of some help in the diagnosis of head injuries complicated by unconsciousness:

UNCONSCIOUSNESS.

- Head injury without breach in scalp or skull.
  - Concussion.
    Pupils equal. Slow, shallow respirations. Pulse slightly slowed or quickened.
  - Cerebral laceration.
    In addition to concussion, there may be homolateral irritability.
    - Intracranial hæmorrhage.
      - Extradural.
        Unequal pupils, stertorous breathing, slow pulse. Initial interval of consciousness. Flaccidity or spasticity of limbs of opposite side.
      - Intradural.
        Symptoms of concussion, coupled with those of cerebral irritation, such as twitchings, convulsions, etc.
- Head injury with breach in scalp and skull without penetration of skull by missile.
  - Concussion.
  - Hæmorrhage, with brain laceration and œdema immediately below injury. Here focal symptoms or symptoms of cerebral irritability, if such exist, are heterolateral.
    - Fractured basis cranii. Hæmorrhage from nose, throat, or ears. Hæmatoma of upper eyelids, and often stertorous breathing, with unequal pupils.
- Head injury, with penetration or perforation of skull by missile. An X-ray in two directions, with wires laid on the Rolandic and Sylvian fissures surface-markings, will show the breach in the bone, the position of the missile, and consequently its path, and from this the damaged tract of brain can with tolerable accuracy be estimated.

Subconsciousness is the result of concussion, hæmorrhage, or brain injury. It is frequently associated with subdural hæmorrhage, but in this case there are present in addition symptoms of cerebral irritation. If the condition be due to a slowly progressive compression, then subconsciousness slowly progresses to unconsciousness, and further symptoms of compression slowly follow. If due to concussion only, then consciousness soon returns.

Consciousness.—Penetrating or perforating wounds of the skull associated with consciousness form one of the most interesting type of war wound. They are often associated with monoplegia (rarely hemiplegia), but they are frequently symptomless. When the patient is conscious the diagnosis is easier.

The first important question that arises is, " Is the lesion post- or precentral ?" If the wound is of the perforating variety, its direction will furnish some idea as to what part of the brain has suffered. If the wound is of the penetrating variety, there is often little indication of the path the missile has taken.

The two tests in determining whether the damage done is in front of or behind the Rolandic fissure are the presence or absence of joint sense and of stereognostic sense. If both these senses are normal, then the lesion is pre-Rolandic ; but if there be loss of joint sense and astereognosis be present, then the lesion is post-Rolandic.

Should the lesion be post-Rolandic, sensory changes and the fields of vision should be investigated. Changes, if present, will point to damage of the postcentral gyrus or occipital lobes.

Monoplegia of the arm, leg, or face, if the lesion be precentral, will denote injury to the precentral gyrus, while aphasia and loss of speech will point to injury of Broca's area. Loss of memory, mental disturbances, and less frequently headache, indicate injury of the frontal lobes.

Injury of the optic chiasma invariably causes complete blindness. Hemiplegia may result from injury of the precentral gyrus or the corona radiata. Injuries involving the internal capsule have invariably been fatal. Injury to the venous sinuses of the brain are either fatal on the battlefield from hæmorrhage or are only manifest at operation, though their presence may be suspected from the position of the wound. Depressed fractures of the skull over these sinuses usually prevent hæmorrhage, and it is when the fracture is elevated or the broken piece of bone removed that an alarming hæmorrhage results.

Injuries of the precentral gyrus are frequently associated with absence of the finger-thumb reflex.

In all conscious cases an X-ray should, as above stated, be taken with wires laid on the surface markings of the Rolandic and Sylvian fissures.

Complications of Head Injuries.

Headache, vomiting, rigidity of the neck muscles, and the presence of Kernig's sign with drowsiness, denote the presence of infection. The temperature rises to 103° or more, a squint may develop, and incontinence may follow. There is one other condition which can simulate these symptoms, and that is cerebral malaria, which is in the East very prone to complicate head injuries. We have in six instances been perplexed, for the symptoms appeared so rapidly in patients who were progressing well. In malaria the onset of symptoms in cases of head wounds has been remarkably sudden, and the temperature much higher than that seen in meningitis, for in two cases it reached 107° and in the remaining cases 105° (not always the case in uncomplicated cerebral malaria). The patients are either noisy or deeply comatose. Meningitis and encephalitis are of more gradual onset, the temperature is lower, and there is not the tachycardia, cachexia, and cyanosis that one sees associated with cerebral malaria. In the case of meningitis, lumbar puncture, which should always be performed, often clears the diagnosis and benefits the patient, whereas in cerebral malaria lumbar puncture does not influence, or has not, in a large number of cases treated in this hospital, influenced the condition one way or the other. On the other hand, large doses of quinine given intravenously and intramuscularly (100 grains in twenty-four hours) has brought about a magical improvement in desperate cases of cerebral malaria, whereas this drug has no effect on the course of an infective meningo-encephalitis.

Hernia cerebri is readily diagnosed by a pulsating, protruding mass of brain substance, which continues to increase in size.

Infection and thrombosis of the venous sinuses are diagnosed by the presence of rigors, the presence of thrombosis of the internal jugular vein if the lateral or petrosal sinuses be involved, and the presence of exophthalmos if the cavernous sinuses be affected.

An occasional sequel to wounds about the optic chiasma is the formation of an aneurysm between the internal carotid artery in its intracranial part and the cavernous sinus. As stated before, we have been concerned in two cases, both being associated with complete blindness and a bilateral pulsating exophthalmos.

Prognosis.

The immediate prognosis of head injuries depends almost entirely upon the immediate symptoms and the time that elapses before treatment is undertaken. If after receiving the wound consciousness be present for any interval, however short, or should a period of consciousness, brief or long, follow immediate unconsciousness, the result of a stun, then the lesion is almost certain to be one of hæmorrhage; and if early surgical measures be undertaken, the prognosis is favourable.

Wounds of the head not involving a breach in the scalp or skull, and

associated with unconsciousness following on an interval of consciousness, are invariably cases of extradural hæmorrhage; and if early surgical treatment is forthcoming, the outlook is good. Should symptoms of cerebral irritation complicate a head wound in which neither scalp nor skull are opened, the prognosis is favourable if early surgical treatment is available.

When scalp and skull are involved, the immediate prognosis is favourable if the case is seen and treated early. Symptoms may be similar—that is to say, unconsciousness may be present following on an interval of consciousness. The longer surgical treatment is delayed, the worse becomes the prognosis in view of septic complications.

Should unconsciousness supervene immediately and be associated with stertorous breathing and a rapid pulse, then the prognosis is invariably fatal.

Penetrating wounds of the skull associated with consciousness and focal symptoms, such as monoplegia, aphasia, loss of memory, and the like, are of favourable prognosis if early surgical treatment be carried out. We would again call attention to the amount of damage and infection the brain can withstand and yet in great part recover itself, if treated early.

Monoplegias, hemiplegias, contraction of the fields of vision, aphasia, and the like, are, in the case of gunshot injury of the head, on the whole of good prognosis. It is not so often the actual damage wrought by the missile that is productive of these symptoms, but the localised cerebral œdema that has resulted from the injury. If the intracranial tension be early relieved by trephining and the wound put under the best surgical conditions, the above symptoms subside from the eighth to the twentieth day. We have now treated many such cases, and the average time for the subsidence of focal symptoms after operation has worked out at ten days.

Fractures of the base of the skull where early or immediate unconsciousness follows are of bad prognosis, although we have had recovery in two cases as the result of early trephining, but in both of these cases an interval of consciousness had existed.

When sepsis is established, the prognosis varies with the portion of the brain infected. If infection has spread to and involved the meninges, the outlook is extremely grave, and but few cases recover. If, on the other hand, the cortex is infected, the infection has shown a tendency to become localised, and on more than one occasion gas has issued from the brain of men who have made complete recoveries and shown no untoward symptoms as late as the end of the third month after operation. Two cases have been heard of nine months later who have not yet suffered any incapacity. Localised encephalitis, therefore, shows a great tendency to clear up after trephining and evacuation of the blood-clot and foreign body from the substance of the cerebral cortex.

Spreading encephalitis, though more the exception than the rule, is of grave significance and invariably ends fatally.

Thrombosis and infection of the venous sinuses form a very fatal complication, and we have not seen recovery in any case resulting from a gunshot wound.

Hernia cerebri, though much less rare than formerly, is a serious complication, but active and efficient early treatment has given such good results that this complication is not to-day the dreaded sequel of brain injury that it used to be.

Silent Cerebral Planes.—Cranial injuries are from many points of view perplexing. While in the line we saw many cases of perforating head injuries, some remaining conscious after injury, though by far the majority were immediately unconscious and died before they could be evacuated. Some conscious cases resembled in almost every detail many of the unconscious so far as the wound was concerned, and this led one of us to make some observations. These observations, gathered from a large number of head injuries seen on the battlefield, and taken under the difficult conditions that exist there, must be taken for what they are worth ; for there was neither time nor, in many instances, was it either safe or advisable to make more refined and accurate measurements. The surface-markings that were taken were the nasion, the occipital protuberance, the parietal eminences, the zygomatic process, the external angular process of the frontal bone, and the mastoid processes. From what we were able to observe over a large number of cases the findings were more than tolerably constant.

The planes through which a missile might pass and emerge, although there was evidently extensive laceration of brain substance, with a quantity protruding from the exit wound, are represented in the accompanying figures.

A point of entry ½ inch above and 1½ to 2 inches outside the nasion, with a point of exit 1 inch above and 1 to 2 inches outside the occipital protuberance, either on the same or the opposite side, form two of the silent tracks. The distance of the point of entry and exit varies within limits of ¾ inch. These, then, are two silent planes (see Fig. 285, *AA*, *BB*).

A point of entry in the same position and within the same limitations in either frontal bone, with a point of exit 2 to 2½ inches behind the external angular process of the frontal bone 1 inch to 1½ inches above the zygoma, form two more silent planes (see Fig. 285, *DD*, *CC*).

A point of entry 1 inch to 1½ inches below the parietal eminence, with a point of exit corresponding to the tracks *CC* and *DD*, is another silent plane (see Fig. 285, *EE*). We were able to discover no silent planes for which the mastoid process was any guide. These planes are of great interest, for in several cases the damage to brain, especially in the frontal region, must have been excessive, judging by the nature of the wound and the amount of brain that was protruding. Similar severe laceration was seen in the planes *AA* and *BB*, yet these patients were not only conscious, but able to walk. The same phenomena were observed in cases

where the track *EE* was present, and this was all the more puzzling, as it is very difficult to see how the motor and sensory areas could have escaped. Yet these men walked, and they were by no means isolated cases.

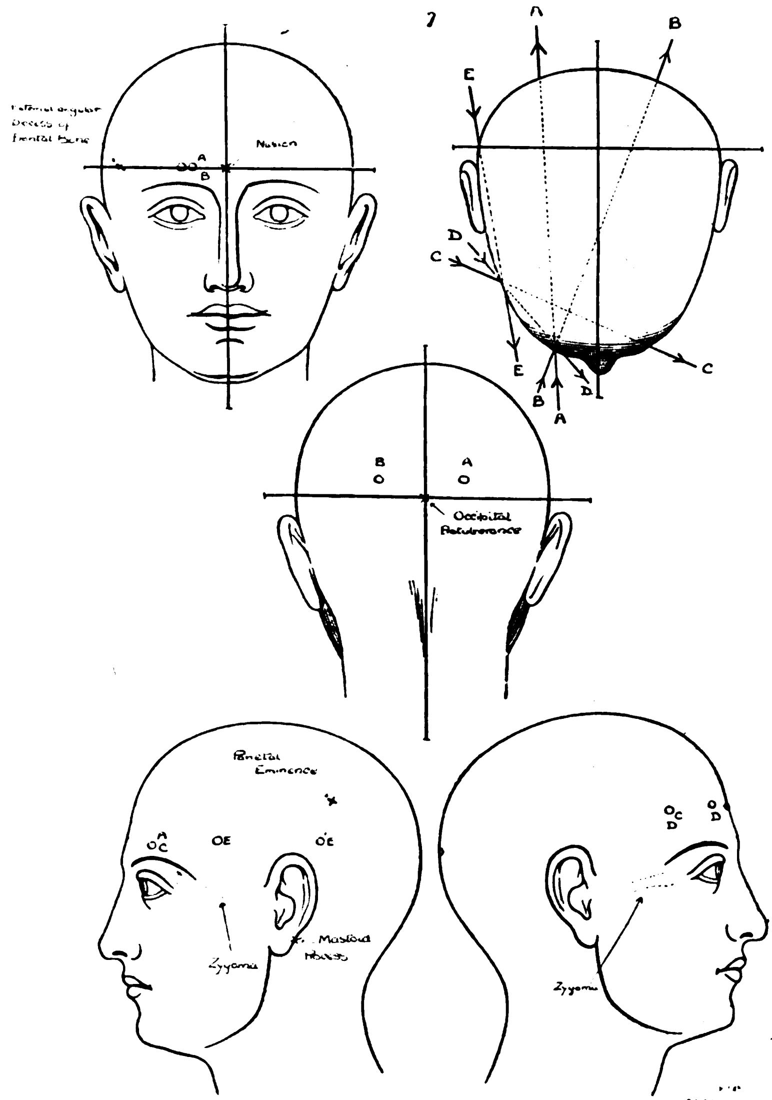


FIG. 285.—Silent planes of the brain.

Other cases in which rough measurements showed the plane to have deviated by ¼ to ½ inch were profoundly unconscious, and died on the battlefield.

We have recorded these observations, rough as they may seem, for these planes seemed so definite and constant as to justify what

appear to be crude and unscientifically conducted observations; but many such observations were made under difficult circumstances and enemy fire; consequently, speed was a necessity, and some inaccuracy inevitable.

Treatment.

Prophylaxis.—Treatment begins on the battlefield, and falls to the lot of the regimental medical officer. An ounce of prevention in these cases is better than many pounds of cure; hence all prophylactic precautions should be taken. The inventor of the steel helmet has indeed proved a saviour of mankind in the present war, and it is little less than marvellous that the incidence of head injuries should have fallen to the degree it has at the time of writing. It should be thoroughly impressed on the soldier that the wearing of his steel helmet is as important to him as carrying his rifle or grenade, and it is the duty of his company officer and platoon commander to make this clear. The importance of keeping the hair as short as possible cannot be too strongly emphasised, and whenever the soldier gets the opportunity of a wash he should thoroughly soap and wash his head. It is in this connection that, apart from the general health, the mouth should be kept as clean as possible, running ears should be seen to, and any suppuration about the nose should have attention.

Treatment on the Battlefield.—The first field dressing should be applied at once, and the wounded man removed as quickly as possible to the advanced dressing station of the field ambulance. It is very important to record on the tally *whether consciousness existed for any time after the man was wounded*, for by the time he reaches the clearing station he may be unconscious.

Treatment at the Advanced Dressing Station.—If there is any delay at this point, the dressing should be removed and the scalp shaved to a distance of 2 or 3 inches from the wound. A eusol dressing should be applied, and the wounded man placed on a stretcher. If time permits, short notes as to his state of consciousness, pupils, breathing, and pulse, should be recorded. Stimulants must be avoided.

Treatment at the Casualty Clearing Station.—It is undoubtedly at this unit that head injuries should receive surgical attention. In a rush this is often impossible, and a number of cases requiring operation pass through to the base hospitals.

Unconscious patients in whom no open injury to scalp or skull exists, especially if information is forthcoming that at one time after injury they were conscious, should be operated upon without delay. Such cases usually show unequal pupils, stertorous breathing, and a slow pulse. Flaccidity of muscles on the opposite side of the lesion, with alteration in the reflexes, may be present, but their early absence in these cases has proved no guide.

All cases of open injury to the scalp should be operated upon. Penetrating

wounds of the skull may or may not present focal symptoms. All such cases should be X-rayed on admission, two pieces of wire being placed, the one on the fissure of Rolando and the other over the fissure of Sylvius. An X-ray taken in two directions will thus give the position of the foreign body in relation to the injury in the skull, and also in relation to the fissures of Sylvius and Rolando.

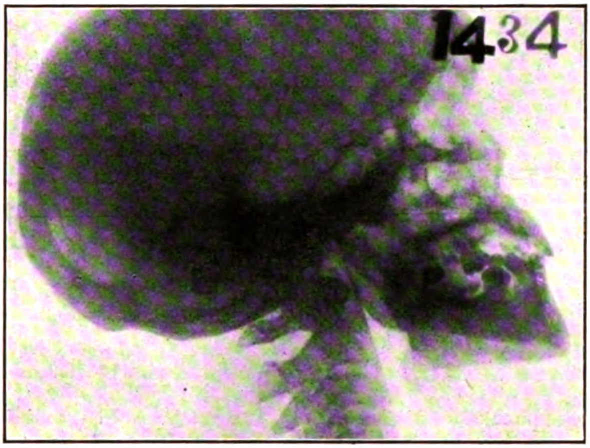


Fig. 826.—Penetrating wound of cerebellum.
Foreign body removed, much offensive gas exuded from substance of cerebellum.

Fig. 287.—Same patient as Fig. 286 six weeks after operation.
Was quite well and walking about two months after operation.

Operation.

The scalp must be cleanly shaved all over, all hair being removed from the neck. This done, the scalp and face are thoroughly cleaned, the former with a scrubbing brush and spirit soap, the wound being protected the while with an antiseptic pad. The cleaning of the scalp has

been usually carried out when the patient is under the anæsthetic, preferably chloroform. When the scalp has been thoroughly washed, it is dried with ether and again rubbed over with biniodide and

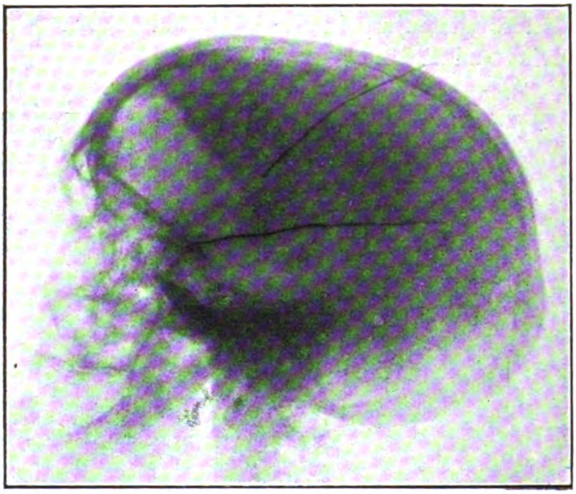


FIG. 288.—Large piece of frontal bone carried away with a portion of the frontal lobe. No symptoms. Fissures of Sylvius and Rolando shown by wires.

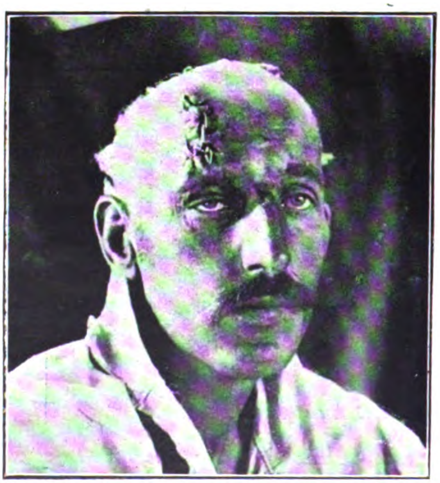


FIG. 289.—Same case as Fig. 288 a month after injury. Wound sterile and sutured. Walking about and no symptoms after two months.

spirit. The scalp must be cleaned right up to the wound edge. The surgeon now changes his gloves, and sterile towels are placed over the patient, one being carefully placed over his face and one over the anæs-

FIG. 290.—Foreign body in occipital lobe.
Point of entry over right eye. The missile traversed the frontal sinus. The only symptom was a paracentral scotoma.

FIG. 291.—Same case as Fig. 290 up and about at the end of five weeks.

thetist's arms. A pad of sterile wool is placed below the towels to absorb any blood. We have not used a head-rest, but have always found a sterilised pillow satisfactory.

The Wound.—The surgeon now proceeds to deal with the wound in the scalp. This should be first sponged out with pure carbolic, or preferably treated with the cautery. This is an important preliminary, because during excision reinfection can easily occur from the weeping of the damaged infected surface over the newly incised surface. Excision of the wound should now be carried out. The scalpel must incise all tissues down to bone, going through tissues ¼ inch outside the damaged edge. The wound must be excised *en masse*. This done, the surgeon takes freshly sterilised instruments, discarding those he has been using.

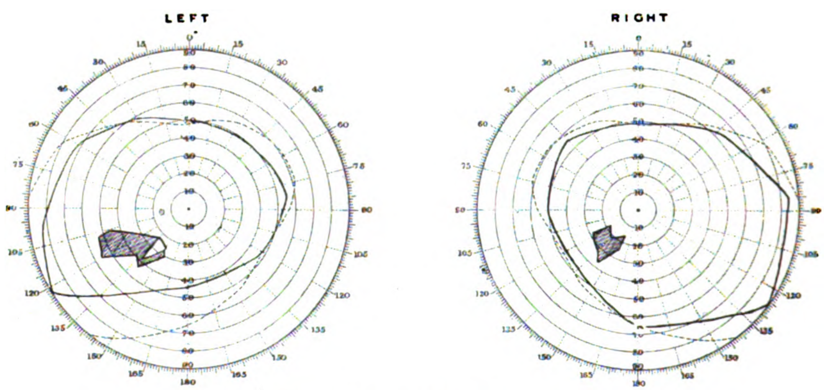


FIG. 292.—Fields of vision of case shown in Fig. 291.
Paracentral scotoma with very slight contraction of the fields of vision.

He now proceeds to examine the skull. If the wound be severe and the patient concussed, but the outer table appear intact as far as fracture is concerned, and provided there be no definite focal symptoms, we are content to go no farther. It is a debated point whether or not all these cases should be trephined, and French surgeons have advised it. We have not taken this view for the following reasons :

1. So many of these cases completely recover without trephining, and to our knowledge have returned to duty showing no untoward symptoms.
2. Although the wound may have been carefully excised and every antiseptic precaution taken, yet the wound was originally septic, and there is always a risk, slight though it be, of infecting the meninges.
3. Should damage have occurred to the inner table and symptoms develop later, then operation can always be undertaken under ideal conditions, for by this time the wound has healed.

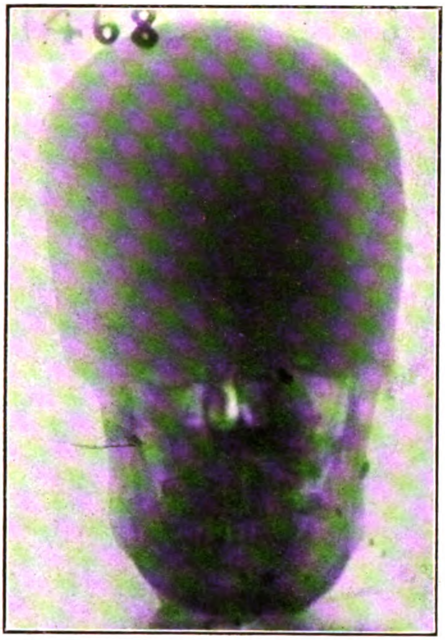


FIG. 293.—X-ray of head injury, showing wound in skull and the presence of numerous foreign bodies. (Antero-posterior view.)

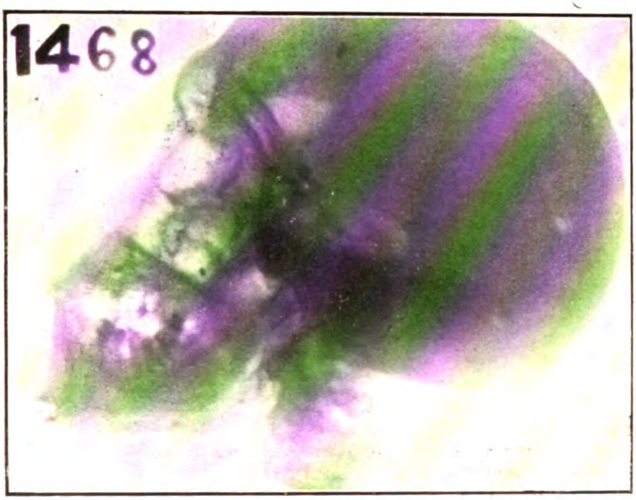


FIG. 294.—Lateral view of case shown in Fig. 293, showing injury to skull and presence of numerous foreign bodies.

Focal symptoms in cases of head injury with an undamaged outer table are rare unless there be extradural hæmorrhage. If this be present, then the skull must be opened.

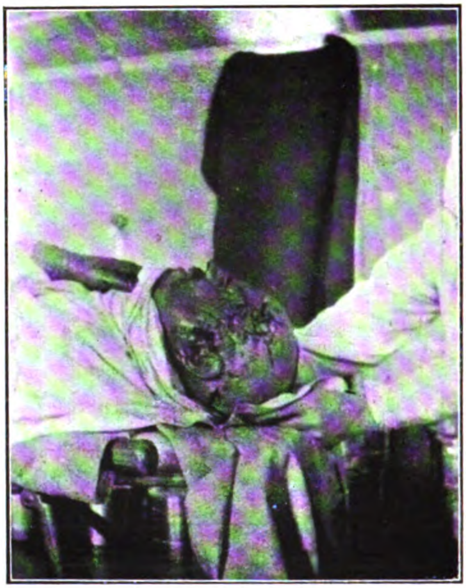


FIG. 295.—Case shown in Fig. 296 immediately after operation.

FIG. 296.—Case shown in Fig. 295.

Large wound of face, eye, and side of head. This patient had severe loss of tissue from face and scalp, and a hernia cerebri on admission to hospital. The whole wound was very septic, and the left eye was destroyed. After sterilisation by Carrel's method, flaps were fashioned, the hernia cerebri removed, and the deficiency in the skull was covered over. The patient made a good recovery, and the photograph is taken three months after injury, when patient was up and about.

If there is no indication for trephining, the scalp after excision of the wound is sutured with interrupted stitches of silkworm gut, without the

inclusion of a small tube. Before suture we have swabbed the fresh wound with either flavine, brilliant green, or eusol. Almost without exception these wounds have healed by primary union.

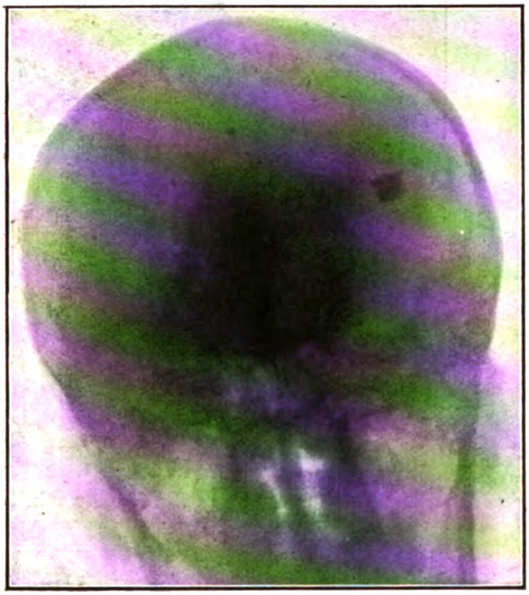


FIG. 297.—Penetrating wound of brain associated with right-sided facial monoplegia.

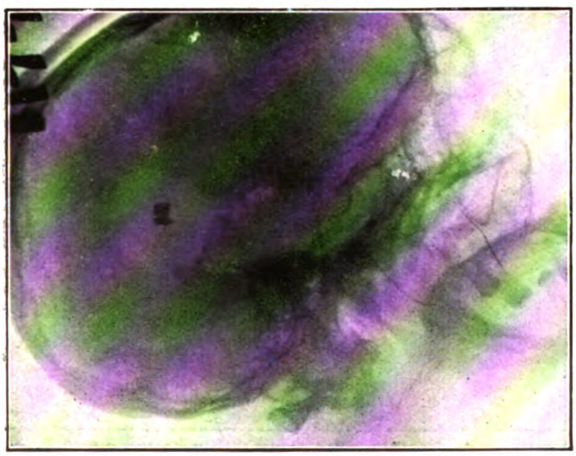


FIG. 298.—Same case as Fig. 297 viewed laterally.

If the wound be extensive, making it impossible to approximate the scalp edges, then the device recommended by Cuthbert Wallace and shown in the illustration on page 497 should be practised, and it has given excellent results.

Trephining.—If there be immediate indications for performing a trephine operation on a case in which the outer table is not fractured, the

FIG. 299.—Case shown in Fig. 298.

Foreign body removed from cerebral cortex at a depth of two inches. Symptom was a left-sided facial monoplegia, which completely cleared up twelve days after trephining and removal of the foreign body. Note the crucial scalp incision.

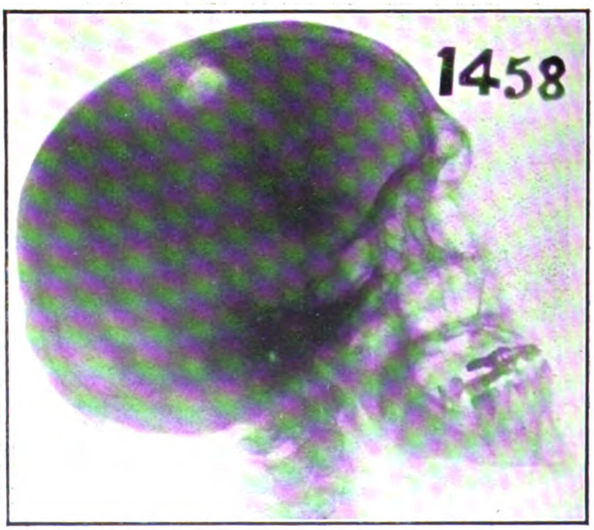


FIG. 300.—X-ray showing lesion of skull.

Symptoms, left-sided monoplegia of arm. Foreign body removed. Missile was a piece of high explosive.

skull must be well exposed. Two methods of accomplishing this are open to the surgeon, for he may either use an omega flap, including the wound

of excision, or he may enlarge the wound of excision. We have tried both methods extensively, and prefer the latter. When once the skull is exposed,

FIG. 301.—Same patient as Fig. 300, showing an extensive scalp wound which has been greatly lessened by the sliding up of a flap.

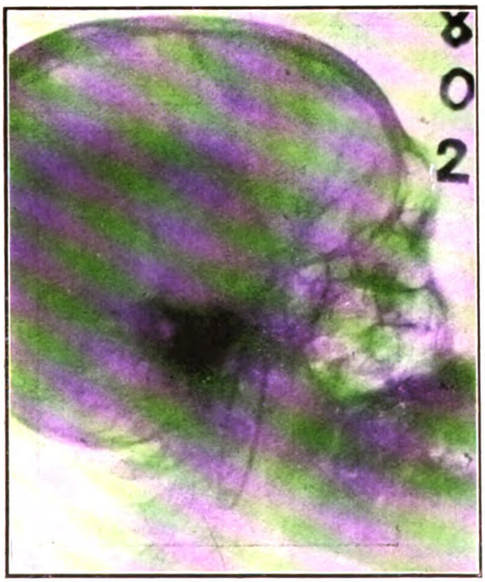


FIG. 302.—Shrapnel ball lodged just to one side of sella turcica. (Lateral view.)

the trephine is applied, and a circular piece of bone removed. It may then be found that the inner table is fractured. The hole in the skull is enlarged with Hoffman's or Horsley's forceps, and all fragments of the inner

table removed. Any bleeding meningeal branch must be ligatured. In these cases it will often be observed that the dura does not pulsate. This is due to cerebral œdema occasioned by the injury, and under no consideration

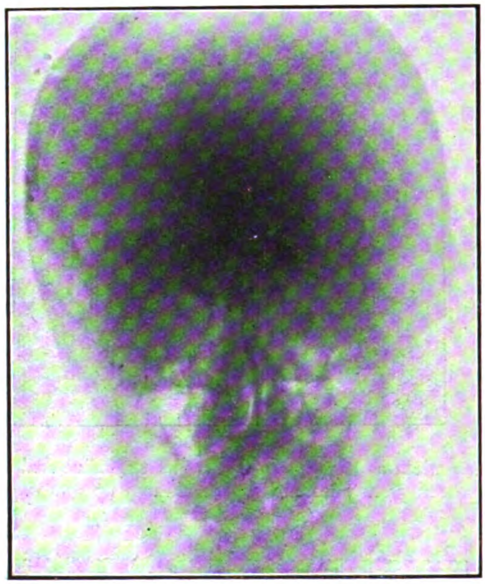


FIG. 303.—Same case as Fig. 302. (Antero-posterior view.)

FIG. 304.—Same patient as Fig. 303. (Front view.)
Note the left-sided ptosis.

should the dura be opened unless there be previous signs of cerebral irritation. The dura may perhaps be damaged, and from the rent some blood-clot is exuded, followed by visible pulsation in the exposed part of the

cerebral cortex. Should this latter condition be present, the dura should be left alone, as probably by this time subarachnoid adhesions have formed. When all loose bone and blood-clot have been removed, the scalp is approximated by means of silkworm-gut sutures, and primary union invariably results. Before suture the wound has been washed out with flavine or brilliant green, saline being employed during the operation. Some surgeons before returning the patient to bed have advocated lumbar puncture, but we have seen no reason to do this.

If no open injury to the scalp has taken place, it is preferable to trephine just as one would do in civilian practice, turning down the usual omega

FIG. 305.—Same case as Fig. 303 after trephining. The missile was not recovered.

flap. The operation in this case is from first to last aseptic, as there is no open infected scalp wound to deal with.

FRACTURE OF THE OUTER AND INNER TABLES.—The first stage of the operation is the same as that in which no fracture exists. The wound of the scalp, after cauterisation, should be completely excised. This done, the trephine is applied, and a piece of bone, including a portion of the fracture, is removed, after enlarging the wound of excision or turning down a flap which includes it. The fractured portions of both inner and outer tables are removed. We have not practised elevation, because the fractured bone is infected. If the missile has not penetrated the dura, nothing further is done. The wound is now washed out with brilliant green, flavine, or eusol, and the scalp is stitched over a very small rubber tube with its ends protruding from the most dependent corners of the

wound. The wound is dressed daily, and eusol is syringed through the tube. At the end of the forty-eighth hour the tube is omitted, and the wound invariably heals *per primam*.

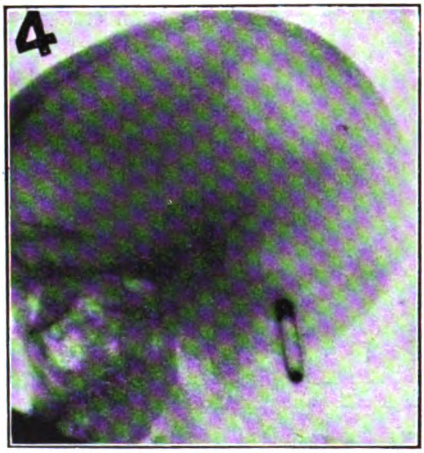


FIG. 306.—A piece of skull carried away by high explosive. Dura mater torn, and large flap of scalp turned down. Paresis of the right leg.

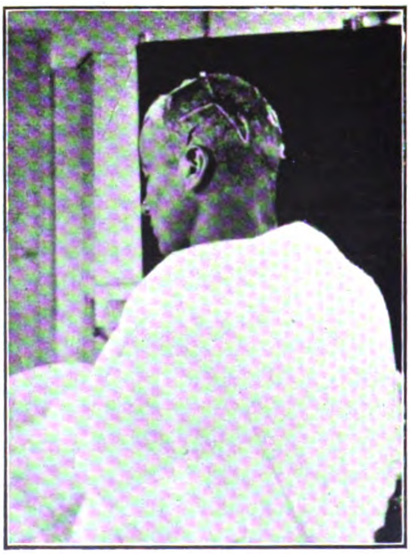


FIG. 307.—Same case as Fig. 306 three weeks later, after suture and healing of the flap. Complete restoration of function in the leg followed.

PENETRATING WOUNDS OF THE BRAIN.—With the X-ray plate before him, the surgeon proceeds first to excise the scalp wound. By means of incisions prolonged from the wound of excision, the hole in the bone is fully exposed

and enlarged with trephine or bone forceps. Enough bone must be removed to show $\frac{1}{8}$ to $\frac{1}{6}$ inch of undamaged dura all round the opening in the skull. At this stage it will be noticed that the dura does not pulsate,

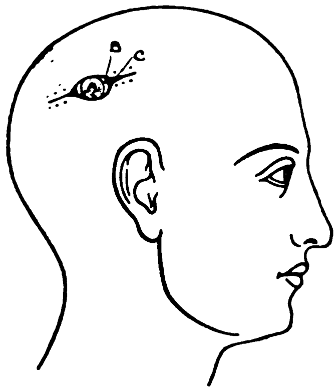


FIG. 308.—Showing diagrammatically the resulting wound after trephining, prior to suturing the scalp.

A, cerebral cortex; B, intact dura mater; C, bone covered with pericranium.

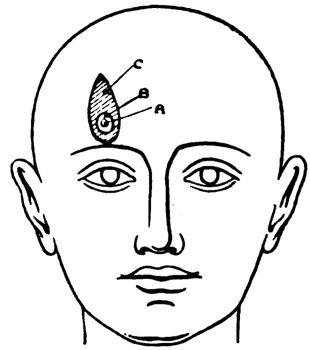


FIG. 309.—Wound after excision and trephining, prior to suturing the scalp.

A, cerebral cortex; B, intact dura mater; C, bone covered with pericranium.

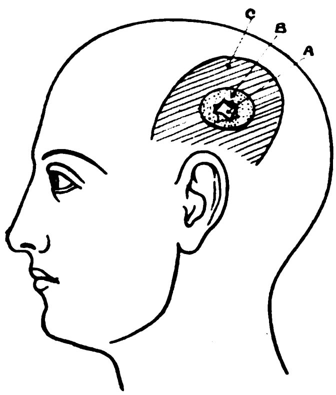


FIG. 310.—Cpl. N——. Wound after trephining and opening the dura for subdural hæmorrhage. Flap omitted.

A, cerebral cortex; B, intact dura mater; C, bone covered with pericranium.

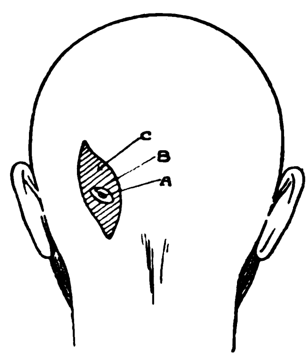


FIG. 311.—Wound of cerebellum after excision and trephining.

A, cerebellar cortex; B, intact dura; C, bone covered with pericranium.

and that the breach in its surface is plugged with blood-clot. Often lying in the breach is a detached piece of bone. When this is removed, the brain "vomits" blood-clot, often accompanied by other pieces of bone from the track. In some instances we have seen it expel the missile.

When once the blood-clot is ejected the brain starts to pulsate, and may be protruded through the hole in the dura.

After carefully measuring the depth of the missile in the brain substance and its direction, a finger is carefully inserted into the track. The trained finger finds its way along the track of the missile until it comes to a cul-de-sac. Here, lying quite loosely, for we have never found it embedded, is the missile. A scoop is now gently inserted along the finger which is touching the missile, and between the finger and scoop the missile is carefully withdrawn.

We have performed several of these operations, and have seen no harm follow the insertion of the finger, provided it be carefully done, neither have we restricted ourselves to the depth to which the finger has been inserted, and in not one case has harm resulted. The walls of the track made by the missile are œdematous, very soft, and, so to speak, give way before the finger.

The whole process must be carried out most carefully and gently, and on no account should a surgeon insert his finger and feel round. This is quite unnecessary, for in a large number of cases we have found that the track leads the finger direct to the missile. Success depends entirely on the sense of touch, and much irretrievable damage may be brought about through the formation of a false track by an inexperienced finger.

Great care must be taken in inserting the finger lest subarachnoid adhesions be broken down, for if this happens, then meningitis may easily follow.

After the missile has been removed the wound is washed out with flavine or brilliant green, and the scalp sutured over a small tube, the ends of which occupy the most dependent parts. In no case have we employed brain drainage, and we have never regretted it. There is not the slightest doubt that the damaged brain, if left alone after operation (provided it has not been unduly stirred up by digital manipulation) and put under the best conditions, can successfully deal with what infection is present, and this our results have proved. Drainage contrivances inserted into brain substance through a wound that was once septic are always paths along which further infection can travel, and we have found them wholly unnecessary.

When all necessary manipulations of the brain are finished, the defect in the scalp must at all costs be closed. It is very bad practice to leave a breach in the scalp with the underlying dura and brain uncovered. In this war, as at other times in the history of surgery, the pendulum has first swung one way and then another. At one time surgeons advocated the practice of leaving head wounds open after operation. There was a reason for this, because at this particular time neither the nature of head injuries nor the type of infection was understood. Bad results followed, for both infection of the exposed dura and brain and hernia cerebri too often occurred. To-day it is the practice to close all head wounds after excision.

has been performed. The procedure has proved both safe and satisfactory when the proper technique has been followed. We still, however, see cases arriving at the base hospital where excision of the scalp wound and trephining has been undertaken at the casualty clearing station, yet the surgeon has stayed his hand at completely closing the scalp wound. This is a grievous mistake, for where such a breach in the scalp is allowed to exist for a period of ten days or more, a degree of hernia cerebri, if not infection, is bound to follow.

If proper excision of the scalp wound has been performed, it is perfectly safe and correct practice to close the scalp defect completely, and so afford protection to exposed dura and brain. Neglect to do this will lead to serious complications.

Closure of the Wound.—It is in the vast majority of cases possible to close the wound in the scalp by interrupted sutures of silkworm gut. If there is liable to be much tension, the scalp should be undermined on either side of the wound. This is best done by inserting the closed blades of a blunt ended pair of scissors beneath the scalp tissues, and then opening them. If this manœuvre is insufficient to allow of the edges of the wound being approximated, then plastic measures must be resorted to. One of the best is the **S** incision recommended by Cuthbert Wallace, and shown in the illustration. Another method is that of making an oblique incision into the scalp on either side of the wound, not involving the pericranium, and sliding the two flaps so formed together over the breach in the skull.

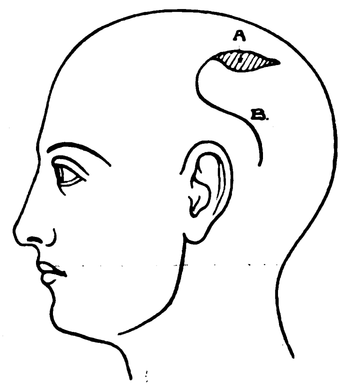


Fig. 312.—**S**-shaped incision for closing defect in scalp.

A, defect; B, **S**-shaped incision.

If the condition is one of fungus cerebri, the wound is sterilised by the Carrel-Dakin method until the count shows two organisms to five fields or lower. When this is the case, the patient is taken to the theatre, the edges of the scalp wound are carefully excised and peeled off the protruding part of the brain. This done, the fungus cerebri is removed with a snare of silkworm gut. There is rarely any bleeding. The edges of the scalp wound are now loosened and sutured over the freshly left brain surface, a small perforated tube being left in the flap, into which eusol is instilled twice daily. Ten of these cases were operated upon, and were detained three months after operation. Every case healed by primary union, there was not an untoward symptom, and every man left for hospital ship able to walk and look after himself, having been up and about for six weeks. At the end of the operation for suture and removal of the fungus cerebri lumbar puncture was performed in each case, and its repetition was not called for.

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These ten cases are of special interest, for before operation they all seemed well, but complained of disturbed and irregular sleep, and while

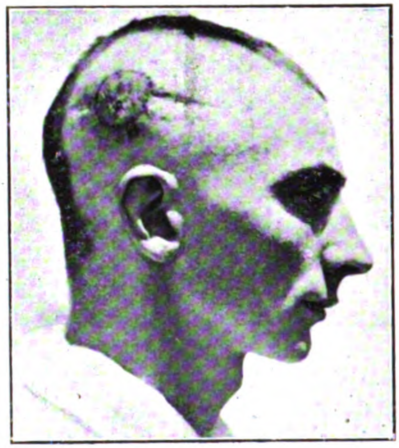

FIG. 313.—Hernia cerebri with left-sided hemianopia and paralysis of left arm.

Dotted line shows position of the hernia cerebri. The hernia was removed and suture of the scalp carried out. Complete recovery of the arm followed, and the eye condition was improving when the patient left for hospital ship three months after injury.

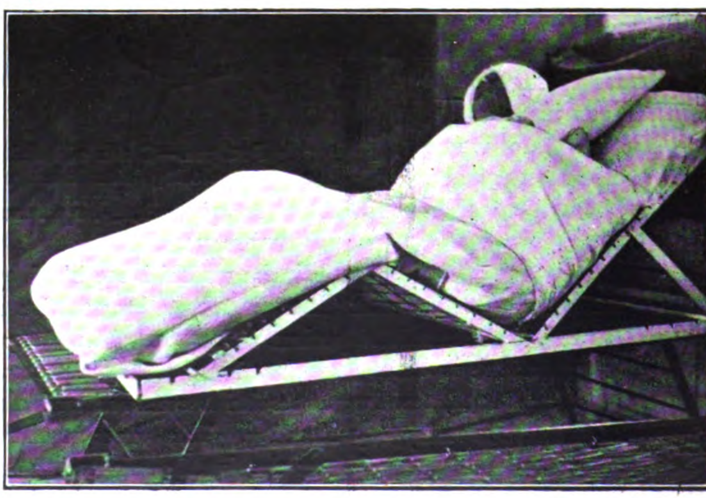

FIG. 314.—Jointed steel bed-frame suitable for the nursing of cases of hernia cerebri or gunshot wounds of the abdomen.

The frame lies upon the ordinary service bed-stand. Whole mattresses, and not the biscuit mattress, are most suitable for this frame.

they slept they suffered from nightmare. After operation these two constant symptoms disappeared.

When a hernia cerebri is large and is tending to become larger, the treat-

ment *par excellence* is lumbar puncture. This measure should be carried out daily, the wound being kept clean with a Carrel-Dakin dressing. The bowels should be kept moving, preferably with hydragogue purgatives,

FIG. 315.—Fungus cerebri seventeen days after infliction of the wound.

FIG. 316.—Fungus cerebri removed and wound sutured and healed.

Same case as Fig. 315.

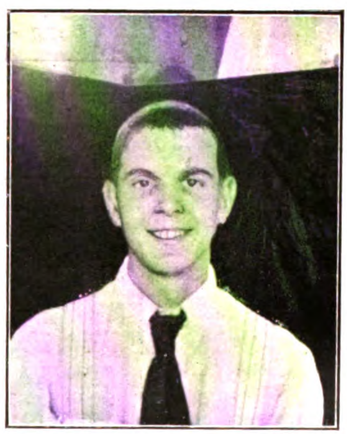

FIG. 317.—Same patient as Fig. 315 two months after infliction of wound, ready to proceed by hospital ship.

and we have always nursed these patients as far as possible in the sitting position, as no doubt gravity plays an important part in reducing the hernia cerebri. The sitting position is easily maintained by means of the folding-bed shown in Fig. 314, and the patients on the whole prefer it. Every

FIG. 318.—Extensive wound of head with hernia cerebri, sterilised by the method of Carrel and Dakin.

FIG. 319.—Same wound as Fig. 318 sutured.

FIG. 320.—Same wound as Fig. 319 three weeks after infliction of the wound. Recovery was complete, and patient left for hospital ship.

possible precaution must be taken to avoid infection, and in this connection the Carrel-Dakin dressing has proved admirably satisfactory.

Under this treatment the hernia cerebri gradually subsides, and eventually becomes a fungus cerebri. When this has happened and the wound is sterile, the operation for fungus cerebri described above can be safely carried out.

On no account should any undue external pressure be brought to bear upon the hernia, and this has never been found necessary.

Cases are described in which, despite treatment, the hernia tends to get larger or remains stationary. Such a case has never come under our care. Some surgeons have in this connection recommended a subtemporal decompression operation on the contralateral side, and this is what would seem the most feasible procedure in the circumstances.

Meningitis and Encephalitis.—Should symptoms of infection of the meninges or cortex supervene, then the best treatment is repeated lumbar puncture. The cerebro-spinal fluid should be examined and cultured, and if possible an autogenous vaccine prepared. These complications, though of necessity grave, are not necessarily fatal. They are frequently due to the presence of an unapproachable foreign body, or they may follow the clumsy removal of a foreign body or a clumsily performed trephine operation. We have seen recoveries take place in what appeared to be hopeless cases, and the surgeon should never despair.

In all cases of head injury urotropine (gr. xv.) must be given three times daily, or in serious cases four-hourly. Calomel (gr. v.) should be administered to all cases of head injury, and mag. sulph. (ʒi.) two or three times a day ensures the presence of a liquid stool.

If the patient is noisy or sleepless potassium bromide (gr. xl.) and chloral hydrate (gr. xv.) may be given in the evening.

Stimulants must be carefully avoided. Easily digestible diet only should be taken for the first few days following operation, and as a routine these men are kept in bed for six weeks. As far as possible, head injuries should be nursed in a quiet ward set apart for them, and if possible the medical officer in charge of the ward and the sister should not be changed, as these patients require special care and treatment, which can only be given by those having considerable experience. The ward should not be too light ; it should be clean, and no other septic gunshot wounds admitted, as the very strictest antiseptic precautions are required in the after-treatment of these cases.

Addenda.

Excisions of head-wounds *en masse* has been recommended by Cushing. In common with other surgeons, he recommends the use of local anæsthesia and extraction of the foreign body, with the contents of the track made by it in the brain substance, by means of suction. The method and technique are described in the *British Journal of Surgery*, April, 1918.

CHAPTER XX

GUNSHOT INJURIES OF THE THORAX

GUNSHOT injuries of the chest, though extremely rare in civilian practice, have assumed a position of importance and frequency in the present war.

Knowing how vital the part of our anatomy is which is formed by the thorax and its enclosed viscera, it seems strange that continuance of function in these parts still persists despite gross damage inflicted upon them by the modern missile.

Thoracic wounds are an object-lesson of the way in which Nature makes good temporarily damage inflicted on important and vital viscera. It is almost incredible how a missile can penetrate or perforate the thoracic cavity in places or along paths which anatomically would seem fatal, and yet the victims of these wounds can walk down unconcerned to the regimental aid post or the advanced dressing station. One of us witnessed instances of two men hit in the chest, who, despite a hæmothorax, nevertheless continued to hold a sap for two hours, throwing bombs all the while.

Many victims of penetrating chest wounds die where they fall, the lesion undoubtedly being one of the heart or great vessels. A number of these cases were the result of snipers' bullets, and most of them presented a very small wound of entry.

During an attack early in 1915, several men were hit in the chest both by rifle and machine-gun bullets while going over the parapet. Some were killed outright, but the majority, who at this stage seemed to suffer but little, were immediately sent to the advanced dressing station. It is difficult to estimate the gross percentage mortality in the case of chest wounds. All the statistics we have are concerned with those who survive long enough to reach the casualty clearing stations and base hospitals, and these form but a fraction of the total. Judging from experience in the line, it would seem that, of the battlefield statistics, the recoveries appear to be greater than the deaths.

If, then, a man sustain a wound of his heart or great vessels, no treatment that can be given him on the battlefield can possibly save him; in fact, "his luck is out." If, on the other hand, these essentially vital

structures escape, he stands a chance, and from observations made both at the clearing station and the base, the chance, on the whole, is in his favour.

Anatomy of the Thorax in Relation to Wounds.

The anatomy of the thorax is such that wounds involving the thoracic contents may easily be complicated by damage to other important structures.

The thorax is a bony cage formed by the ribs, vertebral column, and sternum. The floor is formed by the dome of the diaphragm, with its right and left cupolæ, and the roof, formed by Sibson's fascia, projects from 1½ to 2 inches into the root of the neck.

The diaphragm is a fibro-muscular sheet perforated in several places for the transmission of such important structures as the aorta, inferior vena cava, œsophagus, thoracic duct, and the splanchnic nerves. It is lined for the greater part of its extent superiorly by the diaphragmatic pleura, and inferiorly by the peritoneum. On its convex surface rest the bases of both lungs and the heart, while its concave surface accommodates the right and left lobes of the liver, the spleen, and a small portion of the anterior wall of the stomach.

The dome-like structure of the diaphragm leaves a recess between the lower chest wall and the superior diaphragmatic surface, the costo-phrenic recess. The recessus phrenico-costalis is bounded externally by the lower thoracic parietes lined by parietal pleura, internally by the diaphragm clothed with its diaphragmatic pleura, and superiorly by the base of the lung clothed with visceral pleura.

The roof of the pleural cavities, also domed-shaped on either side, is in close relation to important structures at the root of the neck, such as the innominate artery and vein, the subclavian and carotid arteries, and the large nerve trunks of the brachial plexus.

In immediate relation to the posterior wall of the thorax are the two scapulæ.

The thoracic cavity and its contents never rest. Respiration and cardiac action, in order to maintain the life of the individual, must never cease from birth to death. Normally in the pleural cavities a negative pressure obtains. If there be a breach of continuity in the thoracic parietes, involving their entire thickness, the intrapleural and intrapulmonary pressures become equalised and pneumothorax results.

For the well-being of the individual it is essential that respiration and cardiac action should continue unimpeded. It is well known to what extent pulmonary or cardiac disease can militate against the general health and resistance of any person so afflicted.

In exactly the same manner a severe injury of the lung militates against the satisfactory progress of wounds present elsewhere in the same individual. Thus, we have constantly noticed that large flesh wounds or compound

fractures complicating a chest wound in the same individual take infinitely longer to sterilise and heal than similar wounds in other individuals where no chest injury exists. This is an important point, as wounds in other parts of the body complicating a chest wound should receive more active and energetic treatment.

Wounds of the thorax may be—

A. Contused.
B. Non-penetrating.
C. Penetrating.
D. Perforating.

A. **Contused Wounds** of the chest are usually the result of a direct hit by a spent piece of shell or being buried. The damage done varies from slight or severe bruising of the chest wall up to a simple or compound fracture of bone, with bruising or tearing of the thoracic viscera.

If the blow be sufficient to fracture bone, the fracture may involve the parietal pleura only (subpleural hæmatoma), or it may involve the pleural cavity, causing a degree of hæmothorax (simple fracture). If, on the other hand, the fractured bone involves the lung (compound fracture), then hæmoptysis and hæmothorax result.

Contused wounds of the thoracic parietes are not infrequently followed by a clear effusion into the pleural cavities or by pneumonia.

A contused wound of the chest wall in the region of the spine may cause damage varying from a slight or severe degree of spinal concussion to a fracture of the vertebral column with complete paralysis.

B. **Non-Penetrating Wounds** of the chest vary in degree from simple abrasions to severe laceration both of soft parts and bone. If the wound be oblique and tangential, a number of ribs may be involved. Fracture of the ribs in this connection can either be direct, indirect, or both. If a rib is fractured indirectly, it usually gives at the place of greatest fixation—that is, at or near the angle. If, on the other hand, it is fractured at the site of impact, the blow being tangential, there is not much displacement, but the parietal pleura lining the injured rib is torn. Ribs that are fractured tangentially are very apt to become splintered and to penetrate the parietal pleura, the result being a penetrating wound.

Non-penetrating wounds of the thoracic cavity may involve the vertebral column or even the spinal cord, and give rise either to severe spinal concussion or a complete paralysis below the site of lesion.

Non-penetrating injuries of the chest wall may, through fracture of the ribs, be the cause of a hæmothorax or hæmopneumothorax.

C. **Penetrating Wounds** of the chest vary from a small wound of entry to a severe laceration of the chest wall. Thus, in one case of a soldier killed on patrol duty by the explosion of an enemy bomb, it was only after a diligent search that a very small wound of entry was found in the posterior thoracic parietes. In contrast to this may be quoted the case of

L. Cpl. ——, who in October, 1915, was hit with a piece of high explosive. The left wall of the chest was in great part carried away, leaving the left lung still covered with visceral pleura, and part of the pericardium exposed. This man lived for five hours in the line, but all this time was cyanosed and showed a rapid intermittent pulse. Penetrating wounds of the chest may or may not involve the thoracic viscera. If the heart or great vessels are wounded, death usually is immediate and painless. If, on the other hand, the lungs only are involved, the patient is more often able to help himself, and is early evacuated to the forward units.

Again, a penetrating wound of the thorax may involve the spine or the abdominal viscera, especially those lying in immediate relation to the diaphragmatic cupolæ—viz., the liver, stomach, and spleen.

Most cases of penetrating chest wounds, though not all, are associated with hæmothorax. A penetrating wound of the chest low down may miss the lung, but by traversing the recessus phrenico-costalis may damage the liver, stomach, or spleen. Again, a missile may come to rest in either the anterior or posterior mediastinum without inflicting damage on the viscera. We have seen this latter occurrence in quite a number of cases. It is most frequently associated with fracture of the sternum, the piece of missile being wedged in this bone, or having just penetrated it. By far the majority of cases of penetrating wounds of the chest are associated with fracture of the bony structures forming the thoracic wall.

D. **Perforating Wounds of the Thorax** may show a small wound of entrance and a larger wound of exit. The wound of exit depends upon the amount of damage done to bone, and may vary in size from quite a small opening to a wound of terrific extent which almost passes description. One case will suffice to illustrate this. Pte. ——, while on sentry go, was hit with a piece of shell in the back of the left chest below the inferior angle of the scapula. The missile emerged on the right side, and when one of us saw this man a few minutes after injury he was lying in the trench bottom. The greater part of his right thoracic parietes had been carried away, the exposed lung was flapping about and was soiled with trench mud. He was quickly removed to the regimental aid post a few yards away, where the lung was washed, replaced, and maintained in its place with a boiled towel. He reached the casualty clearing station, and lived for three days. A number of similar wounds never left the line. In all these cases the exposed lung without exception was dark-coloured and engorged.

These wounds, apart from their ghastly nature, presented an interesting side in that the lung does not appear to collapse wholly or cease to function—indeed, the reverse occurs, for these exposed lungs were inflated to a very considerable degree at each inspiration. Without wishing to dwell on wounds so fatal and gruesome, it is of interest and practical importance to record what actually happened in one special case which survived for three and a half hours in the line. This particular man had a large piece of his left thoracic wall and part of his sternum

carried away as the result of the bursting of a trench mortar. The pericardium and lung were exposed, and the main feature in his case was cardiac embarrassment. He was given an anæsthetic prior to dressing the wound, as there was severe hæmorrhage from the internal mammary artery. It was then ascertained that although the lung was exposed, yet it was inflated at each inspiration, and the immediate trouble was due, not to the pulmonary condition, but to cardiac displacement. The displacement was of a rotary character, the apex of the heart having moved to the right and forwards.

This was quite sufficient to bring about an amount of obvious kinking in the pulmonary veins, with consequent engorgement of the affected lung. This engorgement is exactly what occurred not only in those cases which died in the line, but also in the very few that survived long enough to reach the casualty clearing station. It was not until opportunity had presented itself of seeing this one particular case in detail and under an anæsthetic that an explanation of the engorged condition of these prolapsed lungs could be found.

Perforating wounds of the thorax may or may not be associated with damage to the thoracic or abdominal viscera, and the bony frame of the thorax rarely escapes injury. Penetrating or perforating wounds may involve the ribs, sternum, or spine. When the ribs are involved there is usually much splintering of the bone, with a carrying forward of some splinters by the missile into the substance of the thoracic contents. On rare occasions a rib may be cleanly perforated without any splintering, the result of a perpendicular hit with an undeviated rifle bullet, or a notch may be cleanly cut in its superior or inferior aspect. In a number of instances, though these are the exception, the bullet or missile may enter the chest through an intercostal space and so miss bone altogether. Perforating wounds, however, are different, as the exit wound is larger and more ragged, owing to the missile, already *distorted*, hitting the rib on its concave aspect, and now travelling from within outwards.

Immediate Complications of Chest Wounds.

These are—

A. Hæmothorax.
B. Pneumothorax.
C. Chylothorax.
D. Paraplegia.
E. Damage to abdominal viscera.

A. **Hæmothorax.**—This is a very constant complication of almost all penetrating and perforating chest wounds, though it should be borne in mind that in a very few instances hæmothorax, of sufficient degree to give rise to no physical signs occurs.

The extravasated blood may originate either from a damaged viscus (most often the lung) or from arteries in the chest wall (the intercostal arteries and internal mammary). The commonest source of hæmorrhage is the lung, though we have operated upon a number of cases where the

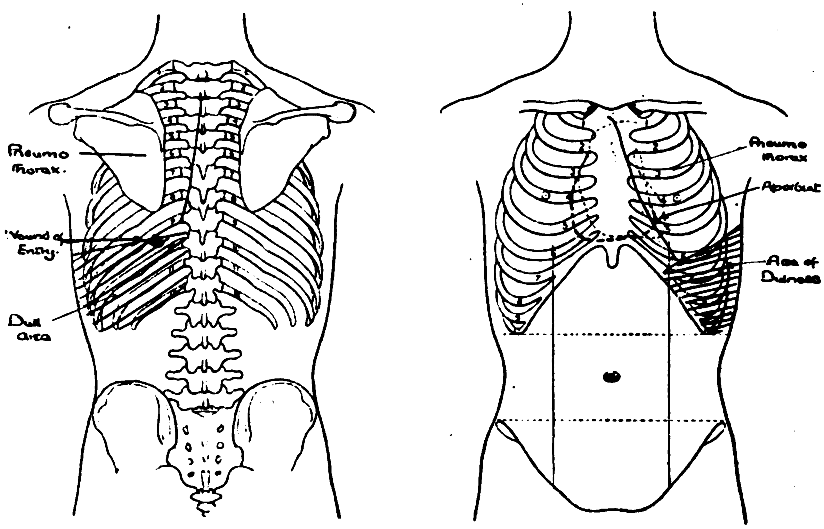

FIG. 321.—Gunshot wound of chest; point of entry left back.
Shaded dull area that of an infected hæmothorax. Upper hyperresonant area that of an infective pneumothorax due to the presence of gas-forming anaerobes. Apex-beat displaced slightly to the right.

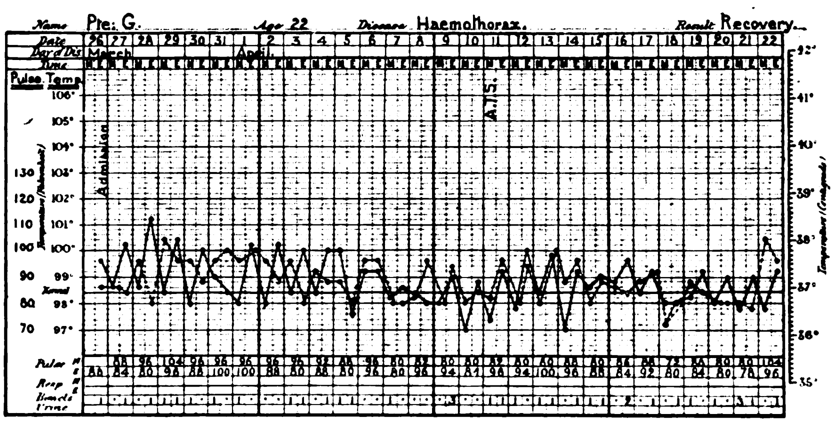

FIG. 322.—Chart showing case of uncomplicated hæmothorax.

bleeding has been taking place from the chest wall. Bleeding from the chest wall into the pleural cavity is seen most frequently in penetrating shell wounds where one or more ribs have been driven in, but in the case of perforating shell or bullet wounds the bleeding from this source is extreme and visible in the wound of exit.

The course of a hæmothorax depends a good deal on what happens to the wounded man in the few hours after he is hit. If he is a stretcher case from the moment he is wounded, the pool of extravasated blood will in nine cases out of ten assume and keep a definite position in the pleural cavity. If, however, he is able to walk and move about for some time after being hit, the position of the extravasated blood will vary accordingly.

As soon as the blood is shed into the pleural cavity, a process of clotting takes place, but it does so in a manner quite different from that which occurs *in vitro*. The constant movement that is going on in the chest keeps the extravasated blood moving, and consequently the clotting process is almost identical with that seen in whipped blood. Fibrin is thrown out and deposited upon the movable structures—viz., the lung, diaphragm, and chest wall. This clot has been called by Elliott and Henry the "primary clot." Later, according to these observers, a further inflam-

FIG. 323.—Photograph of lungs in a case of fatal hæmothorax. Note the collapsed left lung, with fibrin deposited upon it and on the diaphragmatic pleura.

matory effusion takes place into the pleural cavity, which already contains blood devoid of fibrinogen, and which, therefore, does not clot *in vitro*. The latter effusion contains fibrinogen in varying quantity, and gives rise to further clotting in the already existing defibrinated blood. The latter clotting process they have termed the "secondary clot."

If a patient suffering from hæmothorax be kept quiet, the hæmothorax becomes shut off by adhesions formed between the damaged lung and the parietal pleura. The part of the lung beneath the effused blood collapses and ceases to function, whereas the portion unsubmerged shows a compensatory emphysema which may extend across the mid-line of the chest. Thus, the physical signs on the affected side will be dulness to percussion over the localised or non-localised area of effusion, and skodaic resonance almost equal to that of a pneumothorax over the area of compensatory emphysema. Over the area of dulness there are diminished voice and

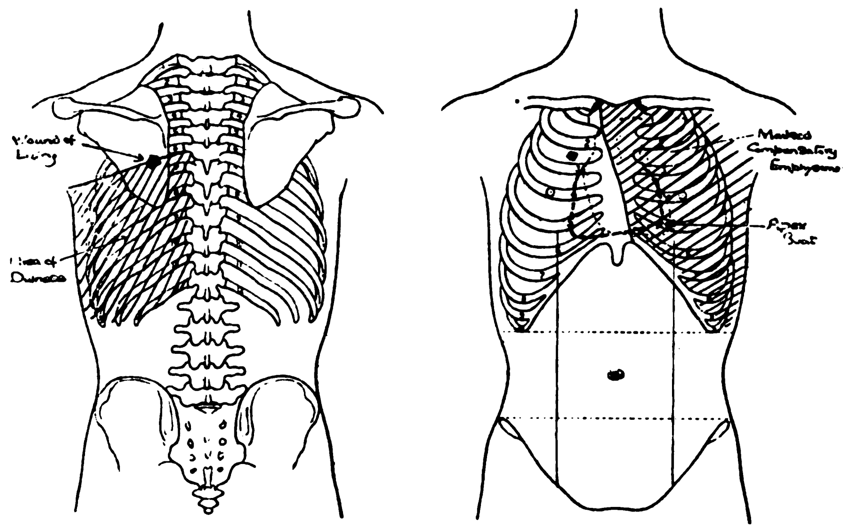

FIG. 324.—Gunshot wound of chest; point of entry over left infraspinous fossa.

Dull area that of hæmothorax. Compensatory emphysema well developed anteriorly and extending across the middle line. Apex-beat displaced to the right. The hæmothorax is here localised by a boundary zone of adhesions.

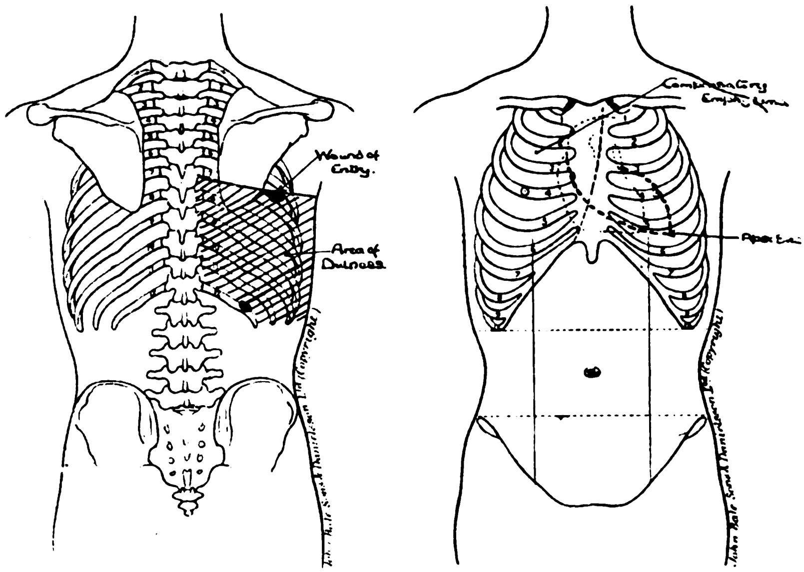

FIG. 325.—Gunshot wound of chest, point of entry being in back on right side.

Area of dulness (hæmothorax) shaded. Apex-beat displaced to left. Marked compensatory emphysema in unsubmerged portion of right lung, extending across the middle line.

breath sounds, and diminished fremitus, whereas over the area of skodaic resonance the breath sounds are extremely harsh and expiration is unduly prolonged, thus distinguishing the condition from one of pneumothorax, for which on percussion alone it might well be mistaken.

The collapsed portion of the lung shows fibrin deposited upon its surface, and if left long enough the fibrin organises and forms a barrier against subsequent expansion. Elliott and Henry, in the *R.A.M.C. Journal* of November, 1916, have pointed out that the portion of the lung collapsed is rarely if ever the seat of infection, and that by submersion in the pool of blood the power of expansion is not permanently impaired.

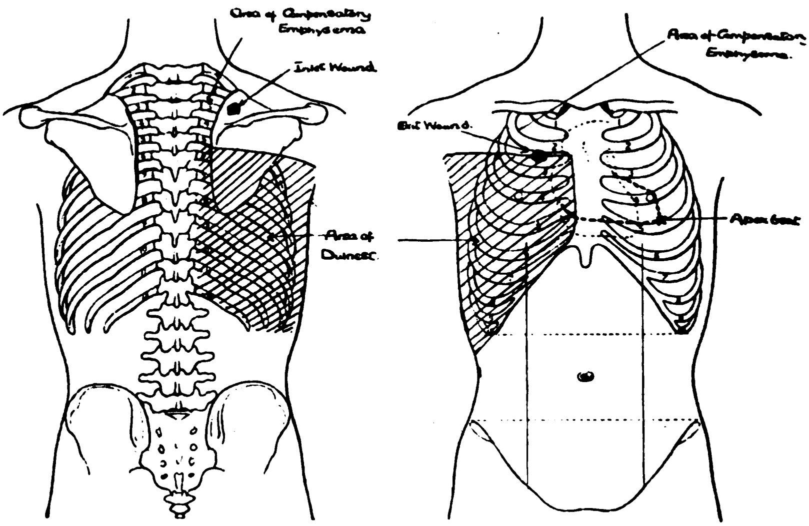

FIG. 326.—Gunshot wound of right chest; point of entry over right supraspinous fossa; point of exit in second intercostal space.

Area of dulness (hæmothorax) shaded. Apex-beat displaced to left. Compensatory emphysema in unsubmerged portion of lung, extending across middle line.

Wounds about the apices of the lungs are generally associated with an extensive hæmothorax, for the effusion of blood into the pleural cavity tends to continue until the whole lung up to the level of the wound in its substance has become submerged. When this is accomplished, further hæmorrhage from the lung ceases.

Such, then, is the simple history of a hæmothorax. From it we can gather some idea of Nature's method of providing rest for the wounded lung, of arresting hæmorrhage, and, at the same time, of compensating for the lost function of the submerged portion of lung, by the production of compensatory emphysema in the unsubmerged portion.

Where old adhesions exist in a pleural cavity, the result of previous disease or a previous wound, the condition of the hæmothorax becomes modified. We may in these circumstances get irregular loculi in the pleural

cavity filled with blood ; or, if the damaged part of the lung be already firmly adherent to the chest wall, then hæmorrhage may occur between the chest wall and the parietal pleura. This, however, is rare. The presence of old adhesions will in the case of hæmothorax prevent collapse of the affected lung.

B. **Pneumothorax.**—This condition rarely exists as an entity in gunshot wounds. It is invariably associated with a varying degree of hæmothorax ; hence, more correctly, the condition should be called hæmc-pneumothorax. Pneumothorax may be either traumatic or infective.

Traumatic Pneumothorax may result either from injury to the chest wall or lung, much more commonly to the former. The breach in the chest wall may be open, as in a thoracostomy wound, or it may be valve-like. It is not at all an uncommon type of chest wound, and, since the prognosis is good, few cases come to autopsy. Pneumothorax, the result of injury to the lung is very rare, hæmothorax being by far the most common sequel of the condition.

Infective Pneumothorax is, unfortunately, in this war a common complication of hæmothorax. It is produced by the presence of gas-forming sporogenous anaerobes in the effused blood. When once these organisms have established themselves in the extravasated blood, gas-formation proceeds at a great pace and a typical pneumothorax results. We have now investigated a number of these cases, and have isolated *B. perfringens* from all of them. It is a noteworthy fact that an infective pneumothorax has never been seen by us in any case where a traumatic pneumothorax existed previously. The explanation of this would appear to lie in free access of air in the latter condition, and the consequent lack of anaerobic facilities for the development of *B. perfringens.* A traumatic pneumothorax soon becomes absorbed when once the hole in the chest wall has been closed, and the symptoms are nothing more than those produced by a thoracostomy performed for conditions like empyema.

Infective pneumothorax is associated with symptoms of grave toxæmia, and calls for immediate thoracostomy and the evacuation of the septic and disintegrated blood-clot.

C. **Chylothorax.**—This is a rare complication, and due to injury to the thoracic duct. In no case have we found this condition at autopsy, but in two cases out of 150 we inferred that this condition occurred, owing to the clinical signs present. Both of these men had small penetrating wounds of the thorax with no symptoms other than *wasting* and some intermittent vomiting and diarrhœa, which lasted about twelve days. Physical signs showed some dulness at the bases. Aspiration was not performed. After five weeks' interval both men commenced to improve and to put on weight, and left in good health for hospital ship eight weeks after their injury.

D. **Paraplegia.**—This very grave, if not fatal, complication may be associated with damage to the lung, and is due to the missile in its course

striking the spinal column. Not uncommonly have we seen paresis and paræsthesia associated with damage to the thoracic cavity, especially where the missile has entered the cavity from behind, in the region of the spinal column, without hitting the spine itself. It often happens that a missile entering the thorax from behind and striking the spinal column carries into the lung broken spicules of bone, and so renders the damage to the lung all the more serious. Such cases are invariably fatal, and if they survive long enough further complications, such as bed-sores, cystitis, and the like, seem to come on with greater rapidity than is the case if an uncomplicated wound of the spine exists.

E. **Damage to the Abdominal Viscera.**—This is by no means an uncommon complication of chest wounds, and usually happens, though not always so, in connection with penetrating wounds of the lower thoracic region. The liver, stomach, and spleen, are the abdominal viscera most often involved, although we have operated upon cases where both the small and the large intestine have been perforated, and two of these by wounds situated high up in the chest wall. The usual course of the missile in this class of case, however, is across the phrenico-costal recess, missing the lung, entering the dome of the diaphragm, and wounding one of the three abdominal viscera mentioned.

We might add that among many cases of chest injury seen by us, both in France and in the East, we have never seen a case of injury to the œsophagus. This may be explained by the fact that the œsophagus is so close a relation of the aorta and pericardium that wounds involving it are almost immediately fatal.

We saw two cases of injury to the intrathoracic portion of the trachea, and though tracheotomy was performed by means of a rubber tube, both cases proved rapidly fatal. One case suffered a fatal hæmorrhage from the left innominate vein, and the second showed a virulent infection of the mediastinum with gas-formation, which was also present in the pericardium six hours after the infliction of the wound.

We saw at a field ambulance a true case of Spannungs-pneumothorax, and confirmed this when the patient was on the operating-table, whilst we were endeavouring to relieve a condition that was rapidly proving fatal. The patient was a German, and the wound proved to be one of the right bronchus, valve-like in nature and communicating with the right pleural cavity. The features about this particular case were the extent of the pneumothorax and the excessive amount of cardiac displacement. The patient took the anæsthetic badly, and after thoracostomy had been performed the rush of air through the valve-like opening in the bronchus could be heard as the patient spluttered in expiration. Further turning back of the chest wall revealed the condition, and during this latter part of the operation the patient died. Owing to the rush of work at that time, further notes or examination could not be made.

Hæmoptysis of varying degree accompanies wounds of the lung. This

is usually so slight and transient that we have not included it as an immediate complication. Cases, however, occurred in the line in which a rapidly fatal hæmoptysis followed certain penetrating wounds of the chest. It is probable that here both a large artery and a bronchus or the trachea had been wounded simultaneously, but the conditions did not permit of further examination. We can call to mind only four such cases, and in all death followed almost immediately.

Subsequent History of Penetrating Chest Wounds associated with Uncomplicated Hæmothorax.—Before proceeding to discuss the remote complications of chest wounds, it is interesting to follow the history of an uncomplicated hæmothorax.

It has been pointed out in preceding pages that the submerged portion of the lung becomes coated on its surface with fibrin from the extravasated blood. Further, if this fibrin be left long enough, it gets tougher and tends to organise. If this condition persisted it would seem that the constricting influence of this organised fibrin would prevent subsequent expansion of the lung, but clinically this is not the case. It would seem that both extravasated blood and fibrin are to a great extent absorbed, but the latter not wholly so. An autopsy performed on a case of death due to septicæmia from a knee-joint injury showed the condition persisting in the chest from a gunshot wound two years previously. The wound in the chest was a perforating one, the entrance being over the superior angle of the right scapula and the exit in the third right intercostal space in front. The following observations were made at autopsy: There is no evidence of collapse of the right lung. The lower lobe shows old irregular adhesions to the chest wall and the diaphragm. The surface of the lower lobe of the lung shows a patchy scarring of the visceral pleura. Congestion of both bases present. Another case more convincing is that of a man whom one of us saw who was hit in the chest early in 1915. He was returned to duty in the line nine months later. After being in the line one month he received a fatal wound in the head. An autopsy revealed adhesions between the lung and chest wall, with the same patchy scarring of the lung. The lung was not collapsed, although after his first injury he had suffered from an uncomplicated hæmothorax.

There is, then, strong evidence to show that the extravasated blood is in time absorbed, the fibrinous envelope of the submerged portion of the lung is fissured, allowing this part of the lung to expand, the final result being scattered and tough adhesions between the submerged portion of the lung and the chest wall.

Out of 150 cases of penetrating and perforating gunshot wounds of the thorax treated by us from start to finish, there have been quite a number of cases of uncomplicated hæmothorax. The history of one such case, watched over a period of two and a half months, will suffice to show the clinical picture, for such cases differed but little clinically.

Pte. —— was wounded on April 24, 1917, by a piece of high explosive

which perforated his left chest. The entrance wound was in the back, traversing the supraspinous fossa, and emerging in the third intercostal space just 3½ inches from the middle line. On admission, four days after the injury, he was dyspnœic and cyanosed. Dulness was present up to a level of 1 inch above both entrance and exit wounds in front and behind, and over this area of dulness tactile fremitus and breath sounds were absent, and voice sounds were distant. The cardiac dulness was present to an extent of 2½ inches to the right of the sternum. The apex-beat was not felt, and the heart sounds were distant and better heard on the right side. Above the area of dulness skodaic resonance was very marked, and extended across the middle line, and over this area the breath sounds were very harsh and expiration most prolonged. True ægophony was not present. The evening temperature reached 102°, returning to 99° in the morning.

At the end of a week dyspnœa and cyanosis had disappeared, but there were no changes in the physical signs. At the end of a fortnight the evening temperature reached to just above 100°, returning to nearly normal in the morning. Auscultation now revealed tubular breathing about the upper part of the dull area.

Four days later crepitus redux was present in the same area. During the next fortnight redux crepitations and bronchial breathing were present, and scattered over the greater part of the dull area in front. In six weeks after the injury the temperature had returned to normal and both distant breath sounds and voice sounds could be heard.

On leaving hospital a month later the temperature was normal, voice and breath sounds were present, though slightly distant as compared with the sound side, but there was a very distinct comparative dulness. The physical signs at this stage were, then, those which are associated with a thickened pleura, but slightly modified. From this case, which differed but little from others of a similar nature, we may infer that an uncomplicated hæmothorax of considerable extent becomes absorbed in from ten to twelve weeks after injury.

Remote Complications of Gunshot Injuries of the Chest.

It may happen, as we have seen on more than one occasion, that a soldier wounded in the chest may be the subject of old pulmonary tuberculosis. If this be the case, an injury may be sufficient to light up the trouble, though this, so far as we have been able to find out, has been rather the exception than the rule.

It may happen that a soldier wounded in the chest has at some time suffered from a previous pneumonia with pleurisy and empyema, leaving him with old fibrous adhesions between the lung and chest wall, and this has not infrequently been the case; or, again, he may have suffered from a previous wound of the chest, leaving him with a condition described in a preceding paragraph. Previous adhesions profoundly modify a chest wound, in that

the hæmothorax tends to become irregular and loculated. Remote complications of chest wounds, with the exception of surgical emphysema, are concerned with *sepsis*, and are as follows :

A. Surgical emphysema.
B. Pyothorax.
C. Pyohæmothorax.
D. Pyopneumohæmothorax.
E. Septic pneumonia.
F. Hæmoptysis.
G. Abscess of the lung.
H. Gangrene of the lung.
I. Mediastinitis and pericarditis.

A. **Surgical Emphysema**.—This may be either localised or of a most extensive kind. Thus instances have occurred where the whole of the face was swollen to such an extent that the eyes could not be opened, and the patient was quite unrecognisable. The neck, chest, thorax, abdomen, scrotum, and thighs, have all been involved, and on palpation the subcutaneous tissues are both crepitant and resonant. The condition, though very distressing to the patient, does not necessarily threaten life. The cause is generally a valve-like opening into the chest wall which admits air during inspiration, but does not allow of its exit in expiration. The smallest of valve-like openings into the chest can give rise to a most extensive type of surgical emphysema. Many such cases have occurred, but we have never seen a death result from this cause alone.

B. **Pyothorax** results from the infection of an extravasation into the pleural cavity which is not necessarily blood. In these cases the lung has not always been damaged, but the condition is the result of infection of an inflammatory or traumatic exudate from the pleura. Such a collection of pus may form either in the pleural cavity or between the lobes of the lung, and may be localised or general. Presence of old adhesions in the pleural cavity tends to an irregular form of loculation.

C. **Pyohæmothorax**.—This condition results from the infection of a hæmothorax. Its appearance is delayed after the occurrence of the original hæmothorax, appearing in our series in from the twelfth to the seventeenth day. The source of infection is either the missile itself, the lung, or the infected wound in the chest wall, the last especially if bone be involved. The onset of the infection of the hæmothorax is evident from the temperature chart, for the temperature at this juncture begins to swing between a higher and lower level, and becomes irregular, a condition not obtaining in the case of an uncomplicated hæmothorax. The patient becomes sallow and ill and rapidly loses weight.

D. **Pyopneumohæmothorax**.—This results from infection of the hæmothorax with sporogenous gas-forming organisms. The condition appears from the fifth to the fourteenth day after injury. The patients are

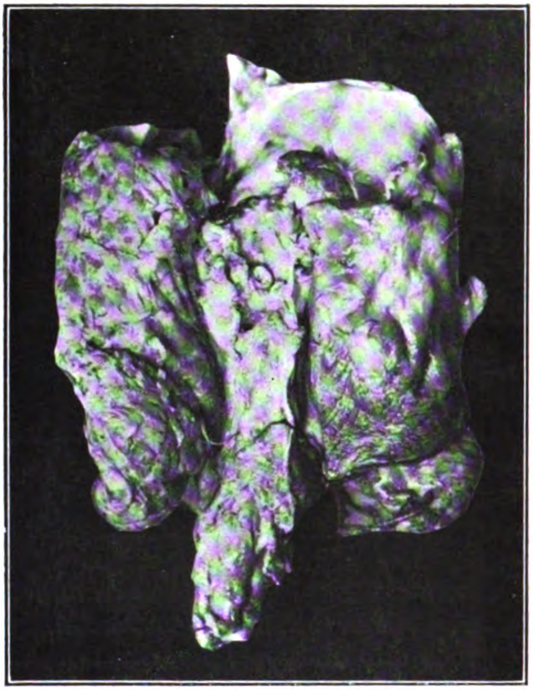

FIG. 327.—Lungs from a case of pyothorax.

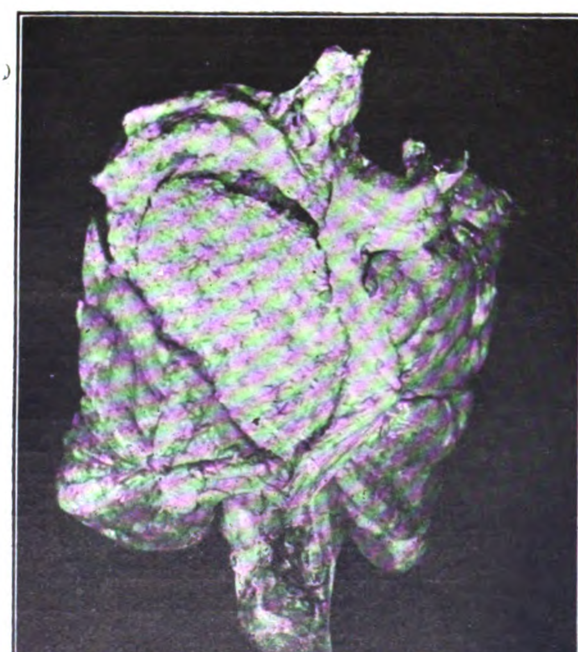

FIG. 328.—Lungs and heart from a case of pyothorax and pericarditis.

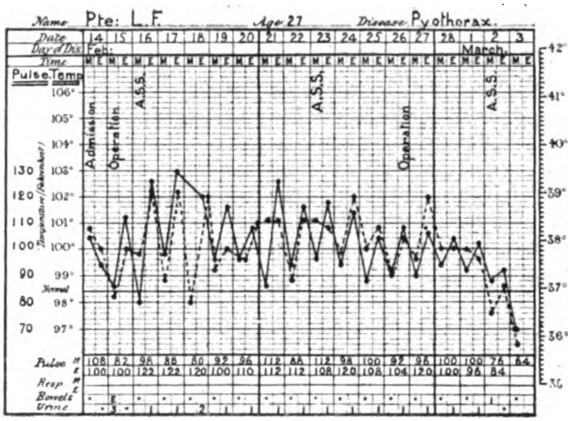

FIG. 329.—Chart of case of pyothorax.

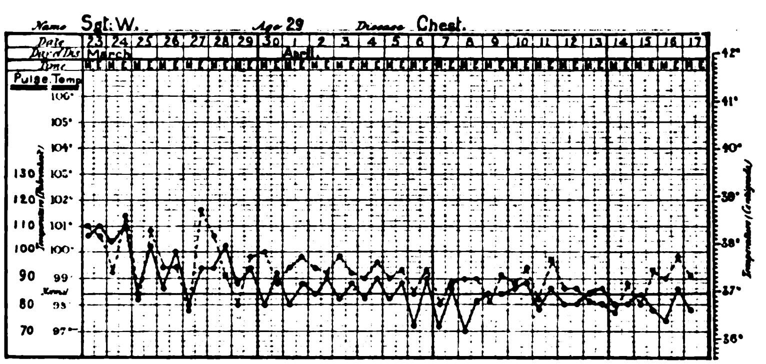

FIG. 330.—Chart of simple uncomplicated hæmothorax.

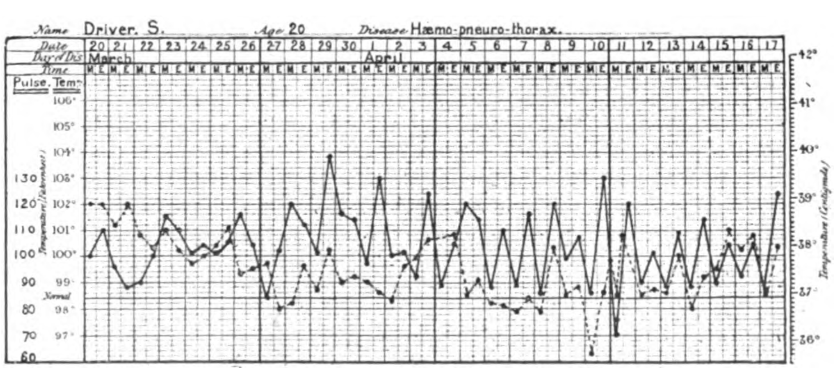

FIG. 331.—Chart of case of hæmopyopneumothorax.

profoundly ill and anæmic; the hæmothorax temperature chart alters to that resembling a pyohæmothorax, but is even more irregular. Classical signs of a pneumothorax appear, in that there is skodaic resonance, transmission of sound, produced by means of coins, across the thoracic cavity, diminished breath and voice sounds, and cardiac displacement. These patients may vomit, the peculiar cyanotic colour so typical of gas infection may be present in the lips, the skin may be sallow or pale, wasting is very rapid, and the condition, unless energetically treated, is very fatal. Infection of the hæmothorax is the result of either the missile itself, or more commonly the wound in the thoracic wall.

E. **Septic Pneumonia.**—This is not at all an uncommon complication of chest wounds, especially when the missile has lodged in the lung and there is no existing hæmothorax. It probably results from infection of the portion of damaged lung around the missile, and from this focus infection spreads. Spread of infection is rendered the more easy owing to the absence of hæmothorax, for the damaged lung is not at rest. This patchy and septic pneumonia does not limit itself to the damaged lung, but it may spread into the sound lung. The condition, when once established, is very fatal.

F. **Hæmoptysis.**—This fatal complication usually occurs from the eighth to the twelfth day after injury, and is nothing more than a secondary hæmorrhage from a damaged lung. The missile, lodged in the lung, causes infection of the damaged lung tissue which surrounds it. Should an artery of any size be included within the damaged area, secondary hæmorrhage results, and the blood is coughed up just as in an hæmoptysis due to pulmonary tubercle. We have witnessed four cases in which the hæmoptysis was brisk and profuse. Three of the cases died and one recovered. Death was not immediate, but followed a few hours later.

G. **Abscess of the Lung.**—Localised abscess of the lung around the missile is not uncommon, and is usually associated with injuries in which hæmothorax has not occurred. The abscess contents, usually of an extremely offensive nature, are coughed up, and a spontaneous cure may result. Usually associated with the expectorated abscess contents is some small amount of blood, but this has never been excessive. The condition, though extremely serious, is not necessarily fatal, the chief danger being a septic spreading pneumonia or gangrene of the lung.

H. **Gangrene of the Lung.**—This is a rare complication of gunshot wounds, and does not occur where hæmothorax is present. In two cases an abscess first formed and was coughed up with a small amount of blood. Following this, gangrene of the lung supervened, and the characteristic pungent breath of both these patients pervaded the ward, necessitating their removal. In one case emboli were disseminated before death. One embolus lodged in the penis, giving rise to a constant painful erection, until the organ became one gangrenous

mass. One man died five days after the onset of the condition, while the other lingered still longer.

It may be mentioned in this connection that gangrene of the lung, to the naked eye similar to these two cases, has occurred from embolism due to gangrene of Vincent's type present in other parts of the body. We can record three such cases, two of which died and one recovered.

I. **Mediastinitis and Pericarditis.**—Mediastinitis is usually brought about by the lodgment of the missile, with its concomitant piece of clothing, in the mediastinum. It is common in connection with fracture of the sternum where the missile has been a piece of high explosive. In three cases gas-formation was well advanced, and death from toxæmia rapidly followed. Two cases recovered, but in both of these the missile was removed early and easily.

Pericarditis is not an uncommon complication of septic wounds of the lung, especially where the streptococcus is present. Infection in this case probably spreads by the lymphatics from the site of injury. This complication is by no means fatal, and a number of cases recover. It has occurred in combination with an infected hæmothorax, but has rapidly subsided when the septic contents of the pleural cavity have been evacuated. Thus it would seem that the pericardium, like other bursal cavities, possesses high resisting powers against infection.

Bacteriology of Chest Wounds.

Wounds involving the chest wall only, without penetrating the thoracic cavity, do not differ bacteriologically from wounds of the body generally. Those involving the heart and great vessels are usually rapidly fatal in the line. Other wounds involving the mediastinum do not usually present any special features of bacteriological interest. From the bacteriological point of view, therefore, it is only necessary to consider here the special problems with those penetrating and perforating wounds of the chest cavity which involve the lungs themselves.

Infection.—The infecting organisms in these wounds are derived from three sources:

(1) *From Without.*—These are carried in with the missile and its concomitant piece of cloth; they present a large variety, being derived largely from fæcal sources. This is the source of the most dangerous organisms, anaerobic gas bacilli, streptococci, etc.

(2) *From the Skin.*—These are sucked in during inspiration in certain wounds in which the opening in the thoracic parietes is not valve-like, but freely open; these organisms consist of the usual skin cocci, etc., and also other organisms of fæcal or other origin—*e.g.*, pyocyaneus—which happen to contaminate the skin at the time.

(3) *From Within.*—These are the habitual organisms of mouth, pharynx, trachea, and bronchi, as well as others which may chance to be

present in these situations at the time of wounding. They include *M. tetragenus*, *M. catarrhalis*, pneumococcus, pneumobacillus, diphtheroid bacilli, and the like.

A large variety of organisms may therefore be present. Indeed, any of those which have been considered in detail in the chapter on the "Bacteria of Wounds" may be found in such wounds; and in the hæmorrhagic fluid present in the pleural cavity, gas-producing bacilli, especially *B. perfringens*, give rise to the greatest amount of trouble.

The hæmothorax which invariably accompanies these wounds of the lung remains *clinically sterile* in the majority of cases which are left alone. "Clinical sterility" implies that, even though a few organisms or spores may have gained access to the fluid, no sufficient growth or development of them has occurred to give rise to the least clinical sign of infection. Such cases may well be left alone, and if they remain clinically sterile, absorption of the fluid takes place gradually without any trouble. When, however, the smallest sign or symptom of infection occurs, and the twelfth to the seventeenth day from date of wound is the critical time, exploratory puncture should at once be performed. Clinical signs of infection supervened in only 28 per cent. of a series of about 150 cases treated by us at a base hospital.

Aerobic Infection.—The infection of the fluid is in some cases a purely aerobic one. This is the type of infection which always occurs, for example, in traumatic pneumohæmothorax cases. In such cases the effused blood becomes altered in colour, and may be hæmolysed or may contain pus.

The infection in these cases usually becomes localised, and the condition resolves itself into an empyema with its accompanying toxæmia. Exceptionally, however, spread of the infection may occur throughout the whole pleural sac, or into the opposite pleural sac or the pericardium. The issue in such cases is complicated. The cases which we have seen of pure aerobic infection have all done well after thoracostomy. In cases of such infection gas is never formed within the pleura or pericardial cavities, even although certain gas-producing organisms of the coli type be present.

Anaerobic Infection.—A purely anaerobic infection has been described, but such cases must be rare. We have not personally seen one. In these cases gas is said to be produced in the pleural cavity, and there is liability to anaerobic toxæmia and even septicæmia, with their well-known clinical features of sallowness, jaundice, vomiting, quick feeble pulse, and tendency to a rapidly fatal issue.

Mixed Anaerobic and Aerobic Infection.—This is, unfortunately, the most common and the most serious type of infected hæmothorax. The anaerobes lying in the effused blood are unable for some time to establish their growth, probably owing to their feeble powers of growing in fresh or unaltered blood or serum. The associated aerobes, however, are able to grow in some cases, and they produce exactly that devitalised

or antitryptic condition of the hæmothorax fluid which is essential for the development of the anaerobes. Gas is then produced within the clot, and may remain as a localised collection for some time, while at the same time toxic products become absorbed by the tissues around the septic and gaseous area. A febrile reaction develops and anaerobic toxæmia occurs. The gas, at first localised, may burst through the clot, becoming generalised throughout the pleural cavity, and it may spread to neighbouring structures, such as the opposite pleura and the pericardium. Such a condition is of the utmost gravity, calling for immediate thoracostomy.

Exploratory Puncture should be performed so soon as the least clinical sign of infection occurs. It is not possible to be sure that infection has not occurred without a bacteriological examination of the fluids. If no fluid is withdrawn, or if the fluid be sterile and show no excess of polynuclear cells, the examination should be repeated after a few days, should suspicious physical signs continue. Sometimes the exploring needle fails to enter the infected area, or it may enter a localised volume of gas, localised blood-clot, or, if old adhesions be present binding lung to pleura at certain points, the needle may pass through these adhesions direct into the lung. In these latter cases no fluid may be withdrawn into the syringe. If sterile clotted blood be drawn off, the needle has most probably entered a vein, for hæmothorax fluid is always uncoagulated, except in some cases where the soft " secondary clot " has formed. This latter can, however, be readily recognised.

Examination of Hæmothorax Fluid.—The physical characters of the fluid should be noted, and a direct microscopic examination made, followed by a cultural examination if necessary.

Physical Characters.—Four types of samples of hæmothorax fluid infected with anaerobes are described by Elliott and Henry :

1. " Blood " with an offensive odour and of an intense purple colour, which is darker and more transparent than that of venous blood. This fluid contains dissolved hæmoglobin from hæmolysis of the red corpuscles, and consequently it will show up a crimson froth in the barrel of the syringe. The crimson-purple colour is in itself almost characteristic of an abundantly growing infection by anaerobic bacilli ; but the foul smell is the chief criterion, and it may be accepted as sufficient proof of infection. From such a sample, on standing, a large flocculent deposit of reddish-brown pus may fall down, but the eye cannot recognise the presence of this pus in the freshly drawn sample. In some of these cases the needle may at first find only offensive gas under pressure, and fail to withdraw any fluid.

2. A fluid that is obviously loaded with pus, reddish-pink or deep buff in colour, and either slightly or not at all offensive.

3. A red fluid like that of an ordinary sterile hæmothorax, and inoffensive. Microscopic examination of this fluid in films shows a moderate

increase in the number of polymorphonuclear cells, and bacilli appear on culture.

4. A yellow serous fluid, with the usual fine gelatinous secondary clot on standing, and the same findings under the microscope as in (3).

From our own experience we would say that in a series of cases in which samples are drawn off when there are suspicious clinical signs of infection, the physical characters of the fluid are briefly as follows:

The fluid may stink, may contain pus, may contain hæmolysed blood (as shown by the permanently crimson froth or crimson supernatant fluid after centrifugalising), or may appear to be simple dark, odourless, coagulated blood. The foul odour, of course, denotes anaerobic infection in every case, and we agree that this is the only criterion of infection that can be accepted at once without further study. Many fluids, however, which are quite odourless, contain not only aerobes, but anaerobes, and in the absence of odour, no matter what the other physical characters may be, further examination is indicated. In a few cases yellow serous fluid may be withdrawn, and extremely rarely chyle may appear, and bear a superficial resemblance to pus.

Direct Microscopic Examination.—This is a very valuable and rapid means of determining whether a given fluid is infected or not. Elliott and Henry found that in 90 per cent. of cases which were subsequently proved by culture to be infected, organisms were found in these direct films. In our own series of cases we obtained a precisely similar result, and found, moreover, that in most of the odd 10 per cent. or so, most of the fluids, although showing no organisms, yet contained a distinct polynuclear leucocytosis, which we came to regard as definite evidence of infection. Thus, by this simple method, which need not take more than a few minutes to carry out, a reliable preliminary report can be given in some 90 to 95 per cent. of the cases.

The technique which we prefer is as follows:

A smear is made from the fluid, or, if necessary, from its centrifuged deposit, upon each of two slides, dried in the air, and fixed by heat. The first is stained by Kühne's carbol-methylene blue for three minutes, and the second by Gram's method.

The carbol-methylene blue stain has already been described, but it may here be repeated that it gives a beautiful picture, by which cells and organisms which are stained deep blue stand out prominently from the mass of red blood-corpuscles, which are stained green. The leucocytes and other cells can be picked out at once in the field, the nuclei much more deeply blue than the cytoplasm, and the organisms, which are also deeply stained, can be very readily picked out, especially if intracellular, when they also show up well against the light blue background of the cytoplasm. If no organisms be seen, a rapid differential leucocyte count can be performed, and the point determined whether any considerable excess of polynuclears exists.

Gram's method of staining, with carbol fuchsin 1 in 20 for the counter-stain, moreover, gives a fair idea of the type of organism present. It is particularly useful for staining the anaerobic bacilli, which stand out as large, stout, Gram-positive, non-sporing, capsulated rods, single or paired —*e.g.*, *B. perfringens*—or large sporing bacilli—*e.g.*, *B. sporogenes*. The presence of such organisms in direct films is for practical purposes in routine work sufficient for a preliminary diagnosis of anaerobes. It must be remembered, however, that sporing aerobes of the *subtilis-mesentericus* type do occasionally occur in hæmothorax fluids. These latter organisms are usually freely sporing, occur in long chains, and have filamentous forms; but these features may also in places be displayed by anaerobes, and these sporing aerobes cannot really be distinguished from the anaerobes by any morphological features in direct films. We have not, however, encountered a single case in which these aerobes were unaccompanied by anaerobes in hæmothorax fluids; and if they do occur separately, it must be a rare occurrence, and the chance of confusing the two groups by the appearance of films is therefore very small.

Certain other organisms can be picked out readily in these direct films. Where organisms are numerous, streptococci, in long or short chains, staphylococci, sarcinæ, *M. tetragenus*, *B. influenzæ*, the groups of diphtheroid bacilli (Gram-positive) and of coliform bacilli (Gram-negative), and sometimes pneumococci (Gram-positive) and large Gram-negative diplococci of the *M. catarrhalis* type can be distinguished. Where organisms are scanty, the cocci, especially streptococci, generally occur in diplococcal form, and are usually all intracellular. Among these the streptococcus, which is the most important aerobe, can usually be picked out by the relatively large oval shape, by the arrangement, and by the Gram-positive staining of the cocci.

Such are the features commonly found in these direct films, and it can be seen that if there be any need for an immediate report, a very valuable preliminary one can be given almost at once; and, indeed, no further examination may be required in a large number of cases. It is obvious, however, that no definite identification of these organisms can be made without cultures, and that cultures are especially required (1) where no organisms are found in direct films, and, for exact work, (2) where stout Gram-positive bacilli are found, for the certain differential diagnosis between relatively harmless aerobes and gas-producing anaerobes.

CULTURAL EXAMINATION.—The following cultures should be put up:

1. *Agar tubes or plate* containing several c.c. of the hæmothorax fluid. The latter fluid is rich in protein, and when it is mixed with agar a culture medium adapted for the needs of the most delicate organisms is obtained.
2. *Litmus milk* made anaerobic by running sterile paraffin oil on the top.
3. *Broth tube* made anaerobic by any convenient method (p. 78).

From the agar tubes or plate the various colonies of aerobic organisms can be picked off, and identified either by microscopic examination or by

further subcultural methods. The *litmus milk* is a most useful medium for the determination of the presence of anaerobes. The most usual reaction where anaerobes are present is the production of the "perfringens reaction" (p. 67), or some modification of it—*e.g.*, that which involves, as an additional feature, the digestion of the casein clot; the latter is a sign of the presence of other organisms. If the "perfringens reaction" be not obtained in typical form, one or two subcultures in milk will often produce the desired effect, and no doubt can then be entertained of the presence of *B. perfringens*. This organism does not spore in milk, and hence it can be killed off by heating the milk culture to 80° C. for half an hour. The latter will then still contain the sporing organisms, which can be recovered by pursuing the investigation in various ways. A convenient method is to subculture into another milk tube made anaerobic, and to examine for the reaction produced by *B. sporogenes*, which is the next most common anaerobe. *B. sporogenes* produces a certain amount of gas and clot in milk, but with a slow digestion and deposit of the clot, leaving a pink, translucent, supernatant fluid after several days. Films made from this culture contain the typical sporing bacilli.

These two organisms can be further identified by the cultural tests given on pp. 68-71, and if pure cultures are desired, it is better to subculture once or twice in an alkaline glucose meat-containing broth before plating out anaerobically upon agar.

By the above milk method the perfringens group can usually be identified within twenty-four hours, and the sporogenes group within a day or two longer. The anaerobic broth culture supplements the milk method, for the latter may fail to yield all the anaerobic organisms present, owing to the excessive acidity which is produced in the milk tube.

From the broth culture anaerobic tube or plate cultures should be made at intervals of a few days up to a fortnight. The saccharolytic anaerobes develop most quickly in the broth culture, and they can be obtained almost pure during the first two or three days. After this the proteolytic group develops more strongly, and within a few days more they come to replace almost completely the saccharolytic organisms.

B. tetani is difficult to obtain in pure culture, but it may sometimes be obtained by plating out from the broth after about a fortnight's incubation. Thus, if anaerobic tube or plate cultures be made from the broth on the third, seventh, and fifteenth days of incubation, colonies of most of the anaerobes present can be obtained. Their further identification depends upon subcultural tests, especially with regard to the sugar reactions.

Summary.

1. In routine work the whole of the scheme detailed above need not be followed.

2. Practical Question I. is, "Is the fluid infected?" The criteria of infection are briefly as follows:

(*a*) *Physical characters*—the presence of odour.
(*b*) *Microscopical examination*—the presence of organisms, or the presence of a definite excess of polynuclears.
(*c*) *Cultural examination*—a growth of any organism.

Practical Question I. can, in 90 per cent. or more of the cases, be settled in a few minutes by the findings under (*a*) and (*b*). In the odd 10 per cent. or so, it can be settled within twenty-four hours by the findings under (*c*).

3. A report on the question whether or not a fluid is infected should be given within twenty-four hours, in order that, in the former case, thoracostomy can be performed forthwith.

4. If the fluid be sterile, the puncture should be repeated in all cases where suspicious clinical signs continue, as the exploring needle may at times fail to withdraw infected fluid, even though the latter be present in the chest.

5. Practical Question II. is, "What is the nature of the infection?" This may be important from the point of view of prognosis and treatment.

A purely aerobic infection is usually the least "dangerous."

A purely anaerobic one is intermediate, and a mixed infection, especially if gross, is the most dangerous, provided that in all cases thoracostomy be performed. The special dangers associated with anaerobic infection are spreading gas gangrene production and anaerobic or ptomaine toxæmia.

7. To decide the nature of the infection the methods of examination (*a*), (*b*), and (*c*) should be followed out, but in the case of (*c*) only so far as may be necessary in each particular example.

The aerobic culture should be made in every case, and for anaerobes the milk method should be used at least so far as to determine the presence or absence of the perfringens and sporogenes groups. These are the important representatives of the two groups of anaerobes. The report on such a modified investigation can be given within two or three days.

Symptoms.

The earliest symptom of a penetrating wound of the chest as seen on the battlefield is hæmoptysis. It is immediate and variable in amount, but as a rule the degree is small.

The onset of other symptoms varies. In a large percentage of cases these men fall when hit, and at first there is a feeling of terror. The facies betokens this, though as a rule these wounded men are quiet and talk little. This early anxious facial expression is a most constant accompaniment of chest wounds. There are, however, on the other hand, the few whom a perforating bullet wound of the chest will not stop, and we have instanced two cases in a preceding paragraph on p. 502.

Symptoms of Hæmothorax.—These will entirely depend upon the

amount of extravasated blood. If the amount be considerable, respiratory distress with a degree of cyanosis will be present. If the amount be excessive, the lips are of a pale cyanosed hue, dyspnœa with air hunger is present, the apex-beat and cardiac dulness are displaced, and with this is superadded cardiac embarrassment.

Physical signs are those of fluid in the pleural cavity, with certain differences, for a hæmothorax, unlike a serous effusion, soon becomes shut off by a zone of fibrinous adhesions formed between the chest wall and lung. Further, the portion of lung which is not in contact with the effused blood rapidly shows a large degree of emphysema. This rapid appearance of a well-marked emphysema is almost pathognomonic of hæmothorax clinically, and this condition has been emphasised by Elliott and Henry from their findings in such cases at autopsy.

There is dulness to percussion, with loss of voice and breath sounds, and loss of tactile fremitus over the submerged portion of the lung, while over the emphysematous area there is a skodaic resonance which would lead one to suspect a pneumothorax. Over this latter area the breath sounds are almost similar to what one hears on putting the stethoscope over the trachea, and expiration is unduly prolonged. This compensatory emphysema often extends across the middle line, and post-mortem findings have shown that the emphysematous portion of the lung is pushed up against the chest wall, leaving the markings of the ribs upon its surface.

The cardiac dulness in extreme cases may be displaced as much as 3 to 3½ inches to the right or left, depending upon which of the two lungs is damaged.

The evening temperature of a simple hæmothorax may reach as high as 102°, returning in the morning to between 99° and 100°, or, on the other hand, the oscillations may not be quite so great.

Where the effusion is small in amount there may be no symptoms beyond dulness rising to a certain level, with a slight rise in the evening temperature. There is no distress, and these patients are comfortable and happy while sitting in a chair.

Symptoms of Pneumothorax.—If the pneumothorax be traumatic, the lung is in part collapsed, and with this there may be cardiac displacement, increase in the respiration-rate, dyspnœa, and cyanosis. To percussion there is skodaic resonance, and to auscultation there are distant or vanished voice and breath sounds. There is also present the *bruit d'airain*, or "clang," heard through the thoracic cavity on the affected side, when coins are clinked together on the chest-wall.

Should the pneumothorax be of the infective type, then, in addition to the above symptoms, there are those of a grave toxæmia. The patient looks sallow, the tongue is dirty, there is loss of appetite, and the temperature is swinging, reaching 103° (rarely higher) in the evening, returning to 99° in the morning. Accompanying these symptoms are evening sweats, and the patient wastes with alarming rapidity.

Chylothorax.—This is a difficult condition to diagnose, as it is invariably associated with a hæmothorax. The only actual proof of the condition existing would rest on examination of some of the aspirated thoracic contents. We inferred that this condition existed in two of our cases of uncomplicated hæmothorax, though we had no direct proof. Both these patients wasted to a remarkable degree, although the chest contents were proved culturally to be sterile. It did not strike us at this particular time to look for fat globules, or make any further examination for the presence of chyle in the aspirated contents. Both patients recovered, having begun to put on weight in the fourth week after injury.

The symptoms of this condition would, then, appear to be rapid wasting and the presence of chyle in the aspirated chest contents.

Pyothorax.—In addition to all the physical signs of fluid, there are superadded symptoms of toxæmia. The temperature is swinging, reaching as high as 103° in the evening, returning to normal or below normal in the morning. The patient is sallow and toxic, his tongue is dirty, his appetite is poor, he sweats at night, and rapidly wastes.

Pyohæmothorax.—The symptoms are identical with those mentioned for pyothorax, except that the evening temperature is not so high and toxic symptoms not so severe. The steady temperature of a hæmothorax after the latter has become infected assumes a swinging character, and may rise a little each evening, coming down lower in the morning.

Pyopneumohæmothorax.—Here the symptoms are those of a combined pneumothorax and hæmothorax, with an infection of a severe type superadded if the pyothorax be infective in origin, but less severe toxic symptoms if the pyothorax be due to traumatism.

Surgical Emphysema.—The symptoms here are those of an inflation of the subcutaneous tissues with air. The inflated tissues are both crepitant and tympanitic.

Septic Broncho-Pneumonia.—Symptoms of this condition differ in no way from those described in textbooks on medicine, and need no further comment here. Should the patient survive long enough, an empyema is very likely to develop, and this should always be borne in mind.

Mediastinitis.—With this condition there are associated pleural friction sounds with pleuro-pericardial rubs. The pleural friction sounds usually occur along the anterior margin of the lung. There is often present a frequent, painful, irritating cough, besides considerable intrathoracic pain. Almost invariably complicating this condition is pericarditis and pleurisy, due to direct spread of the infection to the pericardium and pleura. Mediastinitis is associated with a temperature rising in the evening to 103°, returning to just above normal in the morning.

Pericarditis.—Symptoms differ in no way from those described in textbooks on medicine, and call for no further comment here.

Abscess of the Lung.—A patient may be progressing well up to the fifth or sixth day after injury, when he suddenly becomes seized with dyspnœa

and cough. The expectoration, which is fairly profuse, may consist of odourless or foul-smelling pus, which may or may not be blood-stained. Auscultation will reveal scattered rhonchi and crepitations over an area, the extent of which increases daily, involving further dyspnœa and distress. At this stage the patient may die, or he may survive long enough to show the further complications of this condition. Thus, a day or two later there may be a profuse hæmoptysis, from which death results, or gangrene of the lung, with its unmistakable characteristic odour, may supervene and end the case.

Amphoric breathing in the case of lung abscess following gunshot wounds has invariably been absent, its place being taken by signs of consolidation and scattered crepitations. The crepitations are not confined to the damaged lung, but are present in the contralateral organ. In fact, associated with abscess is almost invariably a septic broncho-pneumonia of both lungs.

Diagnosis.

In the diagnosis of gunshot wounds of the chest great assistance can be obtained from the temperature chart and the general appearance of the patient.

The fact that a patient has a penetrating wound of his chest and has coughed up some blood-stained sputum is sufficient to determine that the lung has been damaged. Cyanosis, dyspnœa, cardiac displacement, with signs of fluid or air in the pleural cavity of the affected side following soon after the injury, will denote the presence of a hæmothorax or of a pneumothorax.

If after the tenth day the temperature becomes irregular, the patient looks ill, and begins to lose weight, it is almost certain that infection of the hæmothorax or hæmopneumothorax has occurred. Should, however, an uncomplicated hæmothorax after the tenth day show symptoms of a pneumohæmothorax, then the presence of gas-forming anaerobes should be suspected.

At this stage a needle should be inserted and some of the pleural fluid withdrawn. This fluid may be either pus (in the case of a pure pyothorax) or chocolate-coloured, with or without an offensive odour (in the case of an infected hæmothorax). Should an evil-smelling, chocolate-coloured fluid be aspirated in the case of an uncomplicated hæmothorax which has developed into a case of pneumothorax, then infection by gas-forming anaerobes is present beyond all doubt. In all cases the aspirated fluid should be sent to the bacteriologist for examination, and the nature of the infection ascertained.

An X-ray will show the position of the missile in the chest, and whether or not it is embedded in the lung tissue, the mediastinum, or the chest wall.

A foul expectoration following on the fourth day after injury, while the missile is still in the lung, associated with an area of consolidation, with

scattered rhonchi and crepitations in one or both lungs, is strong evidence of a lung abscess.

Gangrene of the lung is unmistakable by the pungent characteristic odour of the breath which accompanies it.

An uncomplicated wound of the chest, or wound associated with an uncomplicated hæmothorax, if there be marked wasting with it (a rare event), should arouse suspicion of injury to the thoracic duct. Aspiration should be performed with the object of detecting the presence of chyle in the thoracic contents.

Mediastinitis is readily recognised by the pain it occasions, by the crackling crepitations along the anterior borders of the lungs, by the presence of temperature and pleuro-pericardial rubs, and frequently by an accompanying pericarditis. The position of the missile as shown by X-ray may be of help in the diagnosis.

Wounds of the chest associated with paraplegia or paresis denote spinal involvement. Some cases, on the other hand, are complicated by severe spinal concussion, where the spine itself shows no gross lesion. If this be the case, then the missile may have injured structures adjacent to the spine —*e.g.*, a rib—the concussion occasioned being sufficient to give rise to symptoms of paresis. A lumbar puncture should always be performed in cases of doubt, and the presence or not of blood in the cerebro-spinal fluid ascertained.

Wounds of the chest may or may not involve the abdominal viscera. Many thoracic wounds in which the diaphragm has escaped give rise to abdominal symptoms. Thus, there is rigidity of the abdominal wall on the side corresponding to the lesion, with apparent pain and tenderness of a general kind on palpation, this being due to an attempt to splint the injured side of the chest. Vomiting is almost always absent in these cases, and the patient can pass both urine and flatus ; further, in a few hours the abdominal rigidity and pain pass off. Many wounds of the thorax do, however, traverse the diaphragm and involve the abdominal viscera. The viscera most commonly involved are the liver, spleen, and stomach, though the large and small intestine are not exempt. Persistent vomiting, abdominal rigidity with retraction and inability to pass flatus and urine, are the most constant and reliable symptoms of abdominal injury.

Prognosis.

Uncomplicated cases of hæmothorax invariably do well. The temperature usually settles in from a fortnight to six weeks, depending upon the amount of extravasated blood. Uncomplicated cases of traumatic pneumohæmothorax also do well. The pneumothorax is soon absorbed, and the progress of these patients differs in no way from that of hæmothorax.

Pyothorax, pyohæmothorax, and pneumopyohæmothorax, are serious conditions, and especially the last ; yet if early exit be given to the

infected chest contents the outlook is good. Out of thirty such cases we had five deaths, and of these five deaths three were severely complicated by other wounds. This gives a mortality of 16 per cent. Septic broncho-pneumonia and lung abscess, secondary hæmorrhage (hæmoptysis), gangrene, mediastinitis, with pericarditis, are all very fatal conditions, and unfortunately but few recover.

Surgical emphysema, though of the most extensive kind, vanishes very quickly when once the rent in the chest wall has been closed, and the prognosis is good.

Treatment.

Treatment will depend upon the presence or absence of infection. Infection in chest wounds, as in every type of wound in this war, is the main problem that the surgeon has to face. Many chest wounds as seen at the base hospital do not go on to infection, for out of a special series of 150 consecutive cases, infection occurred in 42—that is, in 28 per cent.

Treatment in the Line will depend upon whether the wound in the chest wall is patent—that is to say, whether there is open communication between the pleural cavity and the atmosphere. If such communication exist, the wound should be immediately plugged with gauze, and a first field dressing or shell dressing firmly applied over this. The wounded man should then be removed to the advanced dressing station as quickly and as quietly as circumstances permit. A quarter of a grain of morphia can be given at once hypodermically, and this should be noted on the tally.

A penetrating wound not involving a direct communication between the lung and the exterior should be dressed, and the wounded man carried back. In a number of instances, during an action, this type of wound has not debarred a man from walking to the advanced dressing station, and apparantly no harm has come of it. During such strenuous times this may be encouraged, for by this means evacuation of the wounded is hastened at a time when stretcher-bearers are busy with more helpless cases.

All cases of chest wounds, as far as it is possible, should be sent direct from the line to the nearest casualty clearing station.

Treatment at the Casualty Clearing Station.—On arrival at this unit all chest injuries are put to bed with as little delay as possible, and are nursed in the upright or semi-recumbent posture. The only conditions calling for immediate interference are (1) severe dyspnœa with excessive cardiac displacement, (2) hæmorrhage associated with a large open rent in the chest wall, (3) chest wounds complicated with injury of the abdominal viscera, and (4) extensive surgical emphysema.

1. **Severe Dyspnœa with Excessive Cardiac Displacement** may be due to one of two conditions :

(1) A traumatic pneumothorax of an extensive kind, due to injury of the chest wall.

(2) An extensive hæmothorax.

Where a pneumothorax exists owing to either an extensive or small wound of the chest wall, the hole in the parietes must, if possible, be closed. If this be impossible, or if it involve an operation which the patient at this stage could not stand, then the hole must be plugged with sterile gauze after excision of the wound. If the wound in the parietes is large, a Carrel-Dakin dressing should be applied after the breach in the wall has been plugged.

Where cardiac displacement and dyspnœa are present, the pneumothorax must be decreased, and this can best be done by fitting a Sprengel's apparatus to the hole in the chest wall, packing carefully around the tube which enters the pleural cavity. Adhesions soon form between the lung and parietal pleura in the neighbourhood of the rent, and the pleural cavity is thus shut off.

In the majority of cases plugging the hole is sufficient, as the air in the pleural cavity is rapidly absorbed, and the absorption brought about by a Sprengel's pump may occasion hæmorrhage if a wound of the lung be present.

When an extensive hæmothorax exists which is giving rise to urgent symptoms, one of two courses may be followed:

(1) Aspiration.
(2) Thoracostomy.

Aspiration is performed in exactly the same manner and with the same aseptic precautions that are observed in regard to aspiration of any bursal sac. The chest wall over the site of the proposed puncture should be thoroughly cleaned with ether soap, then rubbed over with ether, and finally painted over with iodine. The needle should then be introduced through an intercostal space low down in the area of dulness, preferably, in cases of extensive hæmothorax, in the posterior axillary line. The fluid should be drawn off exceedingly slowly, as a rapid evacuation is very apt to be followed by syncope, which may easily prove fatal. Not more than 20 ounces should be drawn off at one sitting, and this is often quite sufficient to relieve urgent symptoms and make the patient more comfortable. Never forget to have brandy and strychnine at hand when performing aspiration.

Dangers attending Aspiration.—These are—

(1) Syncope.
(2) Risk of further hæmorrhage from the lung.

Syncope invariably follows the too rapid evacuation of the chest contents, and if the precaution against this error be observed it will rarely occur. Should it happen, then strychnine (gr. $\frac{1}{30}$) with brandy is the best treatment.

Risk of Further Hæmorrhage from the Lung is a very real danger, and results in aspirating too much material at one sitting. We have seen this

happen in five cases, and at the time of writing we have examined a further case at autopsy. In this last-named case 90 ounces of blood had been aspirated from the left chest (30 ounces per day on three successive days) at the clearing station to relieve respiratory distress. On admission the patient was blanched, and though the cardiac apex was pushed well over from its normal situation, the dyspnœa was more a true air hunger than that due to collapsed lung and cardiac displacement. He died on the tenth day after admission to the base hospital, autopsy revealing the left side of the chest to be full of sterile blood, the whole lung being entirely collapsed (see Fig. 232, p. 508). Here it was evident that as rapidly as the blood had been aspirated it had been replaced by fresh blood, so increasing the dyspnœa. The amount of blood in the pleural cavity, with the 90 ounces that had been aspirated, was sufficient to have caused death, for on admission and during the ten days in the base hospital preceding death this man was extremely blanched. Twenty-four hours before death he showed a bluish-white colour of the lips—that is to say, an element of cyanosis was present. This was undoubtedly explained by the fact that he had now only one lung to aerate a quantity of blood which at the same time was too deficient to supply all the body needs. We have had similar cases which have been extremely blanched owing to a copious hæmothorax, and in which there has been excessive displacement of the apex-beat; but we have often seen recovery take place in these cases without anything being done.

It is a very sound axiom *to avoid aspiration in the case of extensive hæmothorax where the patient is blanched, unless it be absolutely necessary.* The immediate dyspnœa in these cases is usually due to loss of blood from the general circulation. If, however, the surgeon can definitely convince himself that the dyspnœa and distress are due to mechanical causes brought about by the hæmothorax, then aspiration as above described must be undertaken.

Thoracostomy has been advocated in conditions of extensive hæmothorax, the arguments in favour being—

(1) Evacuation of the extravasated blood, and so forestalling a possible pyohæmothorax or pneumohæmothorax.
(2) Procuring collapse of the damaged lung by the pneumothorax produced, and so avoiding any risk of further hæmorrhage.
(3) Possible repair of the damage done to the lung, and removal of the missile.

We think that thoracostomy in cases of extensive hæmothorax has much to recommend it, and though we have not given it a very extensive trial, yet a few of the cases in which it was adopted, so far as we know, did well. Of forty cases operated upon for this condition, we were able to follow through ten of them, the remainder being evacuated from a casualty clearing station with every promise of doing well, though we cannot give

their subsequent history. The ten cases who were kept until they were convalescent followed the ordinary course of a thoracostomy performed for empyema, and in not one of them did we observe further hæmorrhage. The chest wound healed within periods varying from a fortnight to a month, and at the end of six weeks these men left as walking cases for hospital ship, able in every way to look after themselves.

Operation.—After thoroughly cleaning the chest wall and preparing the skin, an aspirating needle with syringe attached is passed into the chest at the lowest area of the dulness, and a small quantity of fluid is drawn off. A piece of rib about 2 inches long immediately above the space that the needle has entered is resected, after peeling off the periosteum in the usual way. A small opening is now made through the parietal pleura, and the contents of the hæmothorax *slowly* evacuated, at the same time slowly inducing a pneumothorax. This proceeds until the pleural cavity is empty of blood and full of air. A large-sized rubber tube is now introduced, which drains any further blood and at the same time maintains the pneumothorax. We have always selected for the site of thoracostomy a point as low down as possible in the posterior axillary line. Dressings are changed daily, and at the end of a week the tube may be omitted and the wound allowed to heal.

Some surgeons elect to perform a thoracostomy higher up, but we can see no advantage in doing this, since any damage which has been done to the lung invariably rights itself when once the lung has collapsed.

We have always employed chloroform anæsthesia for these operations, and have never seen any harm come of its use.

Another method of procuring a pneumothorax to secure the same end is that of simultaneous aspiration and inflation of the pleural sac with an inert gas such as nitrogen. The method can be carried out slowly and without an anæsthetic, and good results have been claimed from its use. The method requires both elaborate apparatus and considerable skill and experience on the part of the surgeon who undertakes it.

Whenever possible, we have invariably left an uncomplicated hæmothorax to Nature, and the more we see of such cases, especially at a base hospital, in which they have for military reasons to be kept until they can walk and look after themselves, the more we are day by day becoming convinced that the percentage of cases of uncomplicated hæmothorax requiring surgical interference is remarkably few.

2. **Treatment of Hæmorrhage associated with a Large Open Rent of the Chest Wall.**—The pleural cavity in this class of wound is necessarily infected, yet, like other serous sacs, it can well resist infection if put under the best conditions to do so. We must then consider both treatment of the wound in the thoracic parietes and treatment of the pleural cavity.

The Thoracic Parietes.—Excision of the wound, after a thorough cleaning of the skin and shaving of the axilla, should be carried out. Broken pieces of rib must, if soiled, be removed, and sharp protruding

ends of ribs must be clipped away with bone forceps. The divided intercostal arteries must be clamped and ligatured and a Carrel-Dakin dressing applied, if it be impossible to close the wound by a primary suture.

The Pleural Cavity.—A small piece of rib is next resected at the lowest point of the pleural cavity, and a large rubber tube inserted. This removes at once any serous exudate which may have collected in the cavity, and which is so apt to become infected. At the same time, a Carrel's tube may be left in the original wound and a 0·25 per cent. solution of the hypochlorite of Dakin can be instilled two-hourly (2 drachms at a time) into the pleural cavity. At the end of seventy-two hours, if the original wound be clean, which should be the case, the lower tube can be omitted and the wound allowed to heal, at the same time discontinuing the instillation of the antiseptics into the pleural cavity.

The original wound should now be dressed with every antiseptic precaution, the hole in the chest wall remaining plugged with sterile gauze wrung out of Dakin's solution, while the wound in the tissues continues to receive the Carrel-Dakin treatment until it is bacteriologically sterile. This accomplished, the hole in the chest wall can either be closed by a suitably devised plastic operation, or it may be allowed to granulate and finally skin-grafted, if necessary.

3. **Chest Wounds complicated with Injury of the Abdominal Viscera.**—A penetrating chest wound must not deter the surgeon from undertaking a laparotomy for the repair of a damaged viscus. Fortunately, a severe chest and abdominal wound rarely coexist; but if they do, the abdominal wound comes first. Chloroform anæsthesia should be employed, and the necessary laparotomy quickly carried out. This done, the chest wound, if necessary, can next receive attention on the lines already laid down.

4. **Extensive Surgical Emphysema.**—This is most satisfactorily treated by excising the valve-like breach in the parietes, and either suturing, or better, plugging the hole in the chest wall with a piece of gauze wrung out of eusol or Dakin's solution. It is surprising with what rapidity the emphysema disappears when once the hole has been satisfactorily plugged.

Treatment of Complications.—Complications most frequently seen at the casualty clearing stations are—

Septic broncho-pneumonia.
Lung abscess.
Mediastinitis and pericarditis.

Pneumonia not only attacks the injured lung, but also the contralateral organ. The outlook in these cases is extremely grave, and the treatment rests with the physician. We have obtained encouraging results in this connection from the use of autogenous vaccines and needling the lung. The latter process consists in inserting an exploring needle into the substance of the affected lung. One puncture of the thoracic parietes will suffice for many punctures of the lung substance. At the same time some

blood-stained fluid is aspirated from the lung, and this forms the substance for the preparation of the autogenous vaccine. Stimulants and expectorants combined with digitalis should be prescribed, and a nourishing, easily digestible diet given.

Lung Abscess.—This extremely grave complication is usually the result of a piece of missile and clothing embedded in the lung, or spicules of bone may be present also. The missile must be accurately localised by means of the X-ray, and a needle inserted with a view to striking the abscess cavity. If this be successful, thoracostomy should be undertaken with a view to removing the foreign body and draining the abscess cavity. We managed this successfully in two cases, though we failed in many others. Both cases died as a result of septic pneumonia which was already established in both lungs. It is hardly worth while anticipating the condition, as so many cases with a foreign body embedded in the lung have escaped complications of this sort, and, after all, lung abscess is not common. Wherever a lung abscess develops as the result of a foreign body, it is, we think, worth while to try and remove the foreign body if the X-ray shows it to be accessible. At the same time, an autogenous vaccine should be prepared and given a trial, as we have had encouraging results from its use in the cases of lung abscess due to septic emboli.

Mediastinitis and Pericarditis.—These two fatal complications, when once established, are amenable to no form of treatment. Treatment here should be prophylactic, and consists in the early removal of the foreign body, if possible, for that is the invariable cause. Mediastinitis with a complicating pericarditis is most often associated with gunshot wounds which have fractured the sternum, and in most cases the foreign body is lying just inside the anterior mediastinum or wedged in between two fractured segments of the sternum. The wound should be excised and a Carrel-Dakin dressing applied.

Cases of chest wounds, if possible, should be kept for from five to ten days, according to severity, at the clearing stations before evacuation to the base, as they stand early removal by transport very badly.

Treatment at the Base Hospital.—The base hospital is concerned with the more remote complications which are invariably the result of infection. These are—

(1) Pyothorax.
(2) Pyohæmothorax.
(3) Pyopneumohæmothorax.
(4) Chylothorax.

In addition, the base hospital receives cases of unresolved, uncomplicated hæmothorax and hæmopneumothorax.

Treatment of Uncomplicated Hæmothorax and Hæmopneumothorax.—By the time the cases reach the base hospital the hæmothorax is localised—that is to say, the barrier zone of adhesions between the unsubmerged margin of the lung and the parietal pleura has formed and the

hæmothorax is shut off. These cases are kept in bed for two or three days after the journey to the base, and are then put into chairs and carried out of doors. No harm has ever come of this, and in every way the patients are better. During the hot season in the East they have slept outside, carefully protected with a mosquito curtain. After ten to twelve days' treatment in bed and sitting up in a chair, they are allowed to get up and walk. Again, this procedure has been followed by the most beneficial results in every case. Chest wounds in the East seem to do better and convalesce quicker than similar cases in the West, and there is no doubt that the warm, dry climate is more suitable to them. At the end of six weeks from the day of their wound these men are fit to travel, and to look after themselves on hospital ship should any emergency happen during the voyage.

TREATMENT OF SEPTIC COMPLICATIONS.—Conditions (1), (2), and (3) call for the same treatment—viz., thoracostomy. Pyothorax may be localised and occur between the lobes of the lung. Any case of an apparently uncomplicated hæmothorax should, if the temperature suddenly become irregular, be submitted to an exploratory aspiration. If evil-smelling contents in the form of a chocolate-coloured fluid or pus be withdrawn, then operation should not be delayed. If, however, a chocolate-coloured and odourless fluid be withdrawn, it should be immediately sent to the bacteriologist for investigation. Should he report infection, then operation must be performed at once. If a case of hæmothorax suddenly becomes one of pneumohæmothorax, this is invariably due to the presence of gas-forming organisms, and evacuation of the contents of the pleural sac is immediately called for.

The operation should be designed so that the drainage can take place from the lowest point of the pleural cavity. The mistake so frequently made is a too high opening, leaving the recessus phrenico-costalis an undrained sump in which septic material collects. We have in addition made one or two small stab wounds into the upper part of the cavity and inserted Carrel's tubes, instilling 1 or 2 drachms of a 0·25 per cent. hypochlorite solution hourly or two-hourly into each. This does no harm to the pleura, and brings about a more rapid sterilisation of the pleural cavity. Further, it causes no distress or inconvenience to the patient.

A week after operation blowing exercises are practised, with a view to expanding the damaged lung, and at the end of the second week these patients are allowed to walk.

The large tube is omitted at the end of the fourth or fifth day, as the use of Carrel's tubes and Dakin's solution very rapidly clears away infection, and there is at the end of this period little or no discharge.

The wound rapidly heals, and these patients are fit to travel and look after themselves at the end of six weeks following injury.

CHYLOTHORAX.—This rare complication calls for no treatment. It is probable that if the thoracic main duct be injured, the circulation of the lymph will be eventually made good via the insula of Cruikshank.

CHAPTER XXI

GUNSHOT INJURIES OF THE ABDOMEN

ABDOMINAL injuries form an interesting and fascinating branch of military surgery, and the ultimate results so far obtained have varied in the hands of different surgeons. This can in part be explained by the different conditions which obtain—viz.:

1. The distance and condition of the roads between the firing-line and the forward units at which surgical measures can be carried out varies considerably in different localities.

2. Some wounds are received during quiet times, others while active fighting is in progress.

3. Some surgeons elect to operate upon the cases that others would leave alone, and their lists may in consequence show a higher mortality.

Type of Missile.—Out of a large number of abdominal wounds caused by every type of missile, those caused by bombs or other kind of high explosive are the most serious; the least serious, if such an expression can be applied to them, are those caused by rifle bullets and shrapnel balls.

Situation of the Wound.—Abdominal wounds suitable for treatment are either of the penetrating or perforating variety. The point of entry may involve the thorax, spine, back, perineum, buttocks, upper thighs, flanks, or the anterior abdominal wall. If the wound be of the perforating variety, the exit wound may occupy any of these situations. Thus, in one case of a penetrating abdominal wound the point of entry was just behind the right clavicle, and the missile (a shrapnel ball) was found beneath the skin of the anterior abdominal wall in the left lower quadrant. We can recall a case of a perforating abdominal wound where the point of entry was over the supraspinous fossa of the left scapula and the point of exit near the apex of Scarpa's triangle on the right side. The missile may take any course, depending upon the position of the man when hit and its own direction with regard to him.

Character of the Wounds.—Almost every type of wound has been seen in this connection, from the small penetrating or perforating variety to wounds of large dimensions involving large areas of the abdominal or thoracic parietes. The abdominal viscera may or may not be damaged despite extensive damage to the abdominal parietes, and conversely,

an apparently superficial contusion of the abdominal wall may involve extensive damage of the abdominal viscera.

Damage done to the viscera varies. In the case of the small intestine many perforations may be caused by one missile. The large intestine, which is a more fixed structure, does not escape injury, though it is rare to find multiple perforations involving it. Wounds of the ascending, descending, and pelvic colons show a marked early tendency to be shut off from the general peritoneal cavity. Multiple wounds of the small intestine show a similar tendency, but owing to their number and distribution this is often impossible; consequently, extravasation with general peritonitis will result.

The gall and urinary bladders have been penetrated in a number of instances, the latter more commonly.

Again, the damage may involve solid viscera. The liver and kidneys have been the most frequently involved, the spleen less often.

It may happen that the viscera escape damage altogether, but that the mesentery is torn. If this be the case, and the rent is considerable, then severe intra-abdominal hæmorrhage is the usual result, and this is extremely fatal in a large peıcentage of cases. Should a large artery be involved, such as the aorta or the iliac vessels, death follows very rapidly.

Wounds in the back giving rise to abdominal symptoms may not have opened the peritoneum. It is very common indeed to find in this connection a retroperitoneal hæmatoma, and in some cases when the missile has bruised the ascending or descending colon a fæcal fistula has formed along the track of the missile.

Infection of Abdominal Wounds.—Small penetrating or perforating abdominal wounds, though inevitably infected, do not show the same degree of infection as wounds in other parts of the body. This is probably due to the greater ability of the peritoneum to deal with infection. In only one case of penetrating abdominal wounds have we seen gas gangrene in the peritoneal cavity, and this had occurred in a hæmatoma that was completely shut off in the right iliac fossa.

Where a retroperitoneal hæmatoma exists, gas gangrene is very liable to occur if the missile and blood-clot are not evacuated.

Large tears of the abdominal wall are just as likely to become infected as large wounds in other parts of the body.

A hæmatoma of the abdominal wall the result of a contused wound is liable to suppurate. A few such cases have passed through our hands, and the infection has proved to be a mixed one, *B. coli* being present in three out of five cases.

Complications of the Abdominal Wound.—An abdominal wound may be complicated by—

(1) Fracture of bone.

(2) Chest injuries.

Fracture of Bone.—The abdominal walls consist of both soft and bony structures. Thus it is not uncommon to find penetrating abdominal injuries associated with compound fracture of the innominate bone, the vertebral column, or the ribs. If the fracture be very comminuted, pieces of bone may be carried in by the missile into the peritoneal cavity and cause grave damage to the viscera. There is also the risk of the fractured bone becoming infected, and this in gunshot wounds is usually the case. Paraplegia may or may not be present if the vertebral column has been injured, but should it occur the prognosis is extremely grave.

Early Observations in Cases of Abdominal Wounds.—Former experience with a regiment has been invaluable in giving opportunities of observing cases of wounded men who die in the line or at the regimental aid post, and so never reach a clearing station or a field ambulance. It also gave opportunities of observing other important points in relation to abdominal injuries. We found that *penetrating abdominal wounds*, with the exception of those complicated by severe intraperitoneal hæmorrhage, *do not at once, or indeed for hours, if kept quiet, give rise to the abdominal symptom-complex*. The symptom-complex is present by the time the wounded man reaches the casualty clearing station, as we witnessed, and after the motor journey this could not be wondered at. What so strongly impressed us was the difference in the general condition of such wounded men seen in the line and seen a few hours later at the casualty clearing station.

So long as the men were not moved immediately, severe shock did not follow for many hours, if at all, in the case of many abdominal injuries.

The following instances seen in the line may be quoted to illustrate how long shock may be delayed even after the most extensive and rapidly fatal abdominal injuries.

Pte. ——, wounded by a trench mortar. Anterior abdominal wall in great part taken away, with complete prolapse of the intestines, which were apparently intact. One of us saw him immediately after it happened. He was lying in the bottom of a muddy trench, and his viscera were soiled. The pulse was slow, regular, and good; he talked sensibly, and having seen his own viscera, asked jokingly if they belonged to him. He drank some brandy and smoked a cigarette. This state of things lasted for fifteen minutes. While trying to fix him up with shell dressings, he quite suddenly collapsed, and died in a few minutes. The change was remarkably rapid.

Pte. —— sustained a large shell wound, tearing open the greater part of his anterior abdominal wall. Complete prolapse of the intestines followed. Five minutes after injury the pulse was 88, steady, and good. The man was conscious and talked sensibly. The viscera were covered as well as could be under the conditions, necessitating some handling, which rapidly induced collapse and death seventeen minutes after injury.

L. Cpl. —— had his abdominal wall torn open by a bomb, exposing

his viscera, which prolapsed through the wound. Seen five minutes after injury the pulse was 88, steady, and good, and there were no symptoms of shock. He asked for a drink, which was given ; he was also given strychnine and morphia. The viscera were lightly covered over. He talked sensibly, expressing himself strongly about the German who had done it. Shock set in after seventeen minutes, and he died a quarter of an hour later.

These are three cases on which the above hurried notes were made at the time. The class of case was puzzling, and the following comments were made by one of us after witnessing somewhat similar cases, many of equal, others of less severity :

" In cases of extensive damage to the abdominal walls, where viscera were wholly or partially prolapsed, it is difficult to explain the *latent interval*, varying from five to twenty minutes, in which the wounded man is cheery, talking, smoking, and able to drink. This is followed by intense collapse quite suddenly, and death rapidly follows. *In not one of these cases was peristalsis observed in the prolapsed viscera.* The pulse and circulation in the mesentery were good. A hot cloth, had it been procurable, would perhaps have been useful, *as the sudden collapse was always associated with handling the viscera*, but this was impossible under the circumstances."

It is almost certain that the majority of penetrating wounds of the abdominal viscera are followed immediately by arrest of gut peristalsis, and unless the gut is full of liquid material at the time, depending upon the time of the last meal and its character, extravasation will be small. Whether stimuli, such as handling the gut, or the shaking of the wounded man during transport, can set up peristalsis in an injured viscus requires confirmation, but there is strong presumptive evidence to show that it does.

We have many times been impressed by the fact that if these wounded men be carefully moved to a place of comparative safety near by—it may be an old trench, a shell-hole, or, more luckily, a dug-out—given morphia, and made as warm as possible, they stand a far better chance of recovery than if hurried back immediately to a casualty clearing station and submitted at once to operation ; we are able to make this statement as a regiment is always early informed of the death of its wounded. Further, we have often had to keep such cases in the line as a matter of necessity ; hence our opportunities of observing them for forty-eight hours or more. This was not a regular practice, because whenever circumstances permitted, all wounded men were without fail taken back with the minimum amount of delay.

There is one exception to what has been said above, and that is the abdominal wound complicated by severe intraperitoneal hæmorrhage. Here shock is immediate and severe, and any operation, to be successful, must be undertaken much nearer to the firing-line than the present casualty clearing stations or field ambulances.

Six of these severe cases were operated upon by one of us in a dug-out

situate in the communication trench. Four died and two recovered. The four who died had sustained severe damage to the mesentery ; the two who recovered were hit in the spleen, and had suffered severe hæmorrhage. Splenectomy was performed in both cases. In this dug-out it was possible to give saline and to keep abdominal cases if necessary. After the battle of ——, from amongst a lot of dead and wounded men a number of the survivors were rescued. The fittest of the survivors were men who were suffering from penetrating abdominal wounds, the result of machine-gun bullets. They could be easily discerned from the other wounded by the fact that they were lying on their bellies ; they could talk sensibly and had good, steady pulses, and this forty-eight hours after being hit. The remaining survivors were extremely toxic and ill, all being the victims of gas gangrene. This was not so in the case of the abdominal injuries, for in not one that we examined could we discover gas infection, and we ascertained from other medical officers that it was not present in cases they had seen.

Many others were dead, having died from what could be seen at a hurried glance to be gas gangrene. The bodies were black, blebbed, and through rapid swelling had burst the uniforms they were wearing, and the stench was characteristic.

Three of the men with abdominal injuries who were rescued had fæcal fistula, apparently of the large intestine.

During the fighting in 1916 some men wounded in the abdomen who had lain out reached the clearing station. A percentage of them developed fæcal fistula ; others had an action of the bowels containing changed blood a day or two after admission ; and one officer passed a shrapnel ball *per rectum* on the sixth day after being wounded. Many of these men recovered without operation and were evacuated to the base.

One case showing the advisability of waiting is the following :

Pte. ——, wounded in the abdomen on July 1, 1916, had been lying out for eighteen hours. He reached the casualty clearing station twenty-two hours after injury. The wound was caused by a small piece of shell, which had emerged. Pulse was 110 and good, and there was localised rigidity and tenderness in the region of the right iliac fossa. There was no vomiting, but the abdominal wall was retracted. The abdomen was opened ; there was no escape of gas, though the small intestine was found to be punctured in seven places.

Plastic peritonitis was localised and well developed, and the great omentum was adherent. Fluid of a reactionary nature was present in the neighbourhood of the injured gut, but there was no escape of bowel contents. The perforations in the gut were sutured, and tubes were inserted down to the wounded gut and into the recto-vesical pouch. The wound in the anterior abdominal wall was excised and the abdomen closed with through-and-through sutures of silkworm-gut. *The small intestine was empty.*

The pulse remained good for twenty-four hours after operation. Vomiting and distension then appeared, and death followed thirty-six hours later.

We feel strongly now that this operation would have been better left undone, and that this man if left alone might possibly have recovered, because his case did not differ in the least from a subsequent number of a similar character which recovered without operation.

Without hesitation we can say that lying out in an old trench, a shell-hole, or any spot affording cover, distressing as it may sound, has been the salvation of a large number of men who have been hit in the abdomen.

Cases of men who were hit in the abdomen during quieter times, and to whom it was possible to give more attention directly after injury, are still more striking.

Though hollow viscera have been involved, these cases are conspicuous by the absence of shock. Two cases that we kept in a warm dug-out developed fæcal fistula. There was only slight distension, and with morphia they were comfortable. Both were evacuated to the base, and as far as we know both recovered, as no intimation of their death reached the battalion.

Cases with damage to hollow viscera, when seen soon after injury, and provided they are not complicated by severe intraperitoneal hæmorrhage, *show a definite and constant area of localised tenderness.* This area is quickly obscured by transport, and by the time the clearing station is reached tenderness has become diffuse, vomiting has commenced, and the pulse-rate increased.

To sum up:

A large number of abdominal wounds not complicated by severe intra-abdominal hæmorrhage do not at once present symptoms of shock. If such cases are not immediately moved and subjected to motor transport, they remain for hours comfortable and present no symptom-complex of peritoneal infection. They are, therefore, after a rest and the administration of saline and morphia, far better able to stand the journey in a motor ambulance, and their chances of recovery are thereby greatly increased. It is just a question of giving the protective faculties of the peritoneum and omentum a chance to assert themselves, so as to minimise risks of extravasation and shock during transport.

Initial Points to be considered in the Case of Abdominal Wounds.

A. Fatigue.—This condition militates strongly against all classes of wounds.

B. The Interval of Time that has elapsed since taking Food.—During active fighting food and drink are necessarily taken irregularly. A wounded man may have been several hours without food, in which case the hollow viscus may be empty when hit. On the other hand, he may be

wounded during the period of active digestion, in which case there is the danger of both extravasation and hæmorrhage.

C. Nature of the Food the Soldier has been Eating.—This may be bully beef and biscuits (the emergency ration), or the ration issued during quieter times in the trenches. In the former case extravasation has proved neither so extensive nor so serious.

D. The Time at which the Bowels were Last Opened.—In the trenches there is a tendency for men to shun the latrine. A number have been hit while there, and the whole surroundings seem to exert an inhibitory effect on the act of defæcation; consequently, when a man is hit he may have three or four days' accumulation of fæcal material in the large bowel. In a large percentage of the cases operated upon, scybalæ as hard as bricks were present in the large bowel and rectum. Their presence forms one of the most difficult complications to deal with in the after-treatment, for they cause distension and a large degree of obstruction. Frequent enemata are required for their removal, and occasionally digital manipulation, a procedure which is both painful and distressing to the patient.

Were it possible to administer an aperient to every man forty-eight hours before going into action, it would undoubtedly favour the chances of those hit in the abdomen.

E. The Nature of the Missile.—Pieces of high explosive are more serious than shrapnel balls or rifle and machine-gun bullets.

F. The Presence of Early Shock.—This practically always denotes intraperitoneal hæmorrhage. These cases are of a very serious nature, and will not stand a motor journey.

G. The Presence of Other Wounds Complicating.—Compound fracture of the bones of the extremities, ribs, innominate bone, and wounds involving the thorax and spine, are frequent complications of penetrating abdominal wounds, and should receive due attention. Their presence only increases shock, and reduces the patient's chances.

H. Position of Greatest Comfort during Transport.—The Fowler position has been advised, but men with abdominal injuries prefer the prone position, and travel this way on a stretcher more easily.

Problem of Transport.—This will depend upon the military exigencies. During active fighting little can be done at the regimental aid post beyond giving morphia. Wounded men must be got rid of, and this may entail carrying them over rough ground, often under heavy fire, until the advanced dressing station is reached. At the advanced dressing station little can be done, owing to the rush of other wounded. The next stage of the journey is by motor to the field ambulance, and thence to the casualty clearing station. Roads may be bad, occasioning much shaking, and the patient's chances are thereby jeopardised.

During quieter times an abdominal case, if necessary, can be kept some time at the regimental aid post, warmed, and given saline. The journey

to the clearing station can be made more gradual, and the chances of recovery are thereby increased.

It should never be forgotten that some men have morphia in their possession, and dose themselves before the medical officer can reach them.

Conditions at the Casualty Clearing Station.—During active fighting many cases are arriving more urgent than abdominal wounds. Such are hæmorrhages, severe lacerations of limbs calling for immediate amputation, cases of gas gangrene calling for similar treatment, thus rendering the operating-theatre unsuitable for cases requiring laparotomy. At the same time the energy of the operating surgeons is being severely taxed, and this cannot favour the best results.

When pressure of work is not so great more time and care can be given to abdominal injuries; consequently their chances are more favourable.

Classification of Abdominal Wounds.—The following classification includes practically all the abdominal injuries seen in the present war:

(1) Wounds associated with severe intraperitoneal hæmorrhage.
(2) Extensive injury of the abdominal wall, with prolapse of the omentum and a portion of the gut.
  (*a*) With perforation of the prolapsed gut.
  (*b*) Without perforation of the prolapsed gut.
(3) Penetration of the abdominal cavity. (It is here that a localised area of tenderness is helpful to the surgeon.)
(4) Perforation of the abdominal cavity. Here the course of the missile is more or less known.
(5) Penetrating wounds involving the peritoneal cavity, but situated in tissues distant from the abdominal walls—*e.g.*, buttock, thigh, perineum, scrotum, and upper thorax.
(6) Extensive wounds of the buttock involving the rectum and peritoneal cavity.
(7) Contusions of the abdominal wall involving damage to the abdominal viscera.

Diagnosis.—Moribund cases arriving at a clearing station with a rapid pulse, pale, sweating, distended, and dull in the flanks, are invariably cases of intraperitoneal hæmorrhage. Often they die soon after arrival; some arrive dead. Those operated upon invariably succumb shortly afterwards. Cases of this kind that we were concerned with died during the interval in which efforts were being made to improve the pulse and general condition prior to operation.

Injuries to hollow viscera show fairly constant symptoms. Pulse varying from 90 to 110, abdominal rigidity with retraction, general tenderness, rarely localised after a motor journey, and persistent vomiting of a greenish-yellow material. The last-named symptom has proved to be the most significant and constant in connection with wounds of hollow viscera, for the persistence and degree of the vomiting seems to vary with

the amount of extravasation. There is no passage of flatus or urine, and a peritonitic facies is present.

Purely thoracic injuries resemble in some respects abdominal injuries. They differ in that these patients do not vomit persistently ; the abdominal rigidity is unilateral, corresponding to the same side as the chest wound. Urine and fæces are passed. There may be hæmoptysis and cyanosis, with cardiac displacement, respiratory embarrassment, and a short irritating cough. It should, however, never be forgotten that a chest wound may involve an abdominal viscus.

A wound in the back resulting in a retroperitoneal hæmatoma is often very difficult to differentiate from a penetrating wound of the abdominal cavity. Laparotomy has frequently been performed for this condition, and blood has been found free in the peritoneal cavity, although the peritoneum has itself been uninjured.

With the latter cases it is very rare to find retraction of the abdominal wall. On the contrary, there is distension of the gut of an apparently paralytic kind, which recovers itself in five or six days' time. We performed laparotomy on a few such cases, and in all a paralytic condition of the gut with distension existed, although the gut itself was uninjured. The condition is probably due to trauma, or pressure of extravasated blood upon the retroperitoneal plexuses. Vomiting, sometimes of a persistent nature, is not uncommon. There is not the same superficial tenderness to palpation, and rigidity is present to a lesser degree. It is generally possible to palpate the posterior abdominal wall, and it is then that tenderness is elicited.

Abdominal distension and not retraction, definite tenderness on deep palpation when the posterior layer of the peritoneum is touched, with the absence of superficial tenderness, are the main points in the differential diagnosis between a retro-peritoneal hæmatoma and an injured viscus.

Wounds of the anterior abdominal wall which do not penetrate the peritoneal cavity may be associated with damage to a viscus. One case presented a severe tear in the liver, and in another the cæcum was torn. In every case of injury to the abdominal wall not involving the peritoneal cavity it is wise to wait a few hours and watch for developments. If complications of an internal kind do not arise after three or four hours, it may safely be assumed that there is no intra-abdominal lesion.

Wounds of the thorax, thigh, buttock, and perineum, may involve the peritoneal cavity, and this should always be borne in mind.

Treatment—On the Battlefield.—Treatment commences at the time and place at which the wounded man falls. When active fighting is in progress the regimental medical officer can do little on the battlefield besides loosening the kit, giving morphia, and taking away the water-bottle. These men must often wait until after dark before they can be rescued or taken to a place of cover, but occasionally a wounded man with a loop of intestine prolapsed has been known to walk to the

advanced dressing station. When the advanced dressing station is reached, further morphia should be given if necessary, prior to the journey to the casualty clearing station. This should be carefully noted on the tally, and if time and opportunity permit, the localised area of tenderness which is always present at first should be marked out with a skin pencil on the anterior abdominal wall. This is invaluable information to the surgeon at this last-named unit, as the local tenderness practically always disappears by the time the unit is reached.

During quieter times the regimental medical officer can give abdominal cases more attention. In the line we found it possible to get them warm and give them subcutaneous saline before sending them on to the advanced dressing station.

When severe intra-abdominal hæmorrhage has taken place, the patients stand the journey so badly that, if possible, it is advisable to operate at the advanced dressing station, or even at the regimental aid post, for by doing so, life is undoubtedly saved. As mentioned before, two cases recovered

FIG. 332.—Drawing of a piece of small intestine resected in a dug-out in the line. The wound was caused by a rifle bullet. There was severe intraperitoneal hæmorrhage. Note the nature of the wounds.

out of six operated upon in a dug-out not far behind the front line, for in truth none of these six men would have survived carrying to the advanced dressing station. They were all operated upon within ten minutes after receiving their injury.

The bad results of similar though less severe types of wound which survived to reach the casualty clearing station must teach us that the practice of immediate laparotomy, although performed by us in only six cases, is not only possible under the conditions, but that it is the correct practice in order to save life.

Men after operations other than laparotomy which were of necessity performed in the line have slept well under morphia prior to their removal to the advanced dressing station, despite the continuous din of artillery.

A number of cases of injury to hollow viscera which owing to battle conditions were kept in a specially constructed dug-out, made warm, given saline and morphia, and sent down a few hours later to the

advanced dressing station, reached the field ambulance and the casualty clearing station in a very good condition, and it was noticeable that cases which had received this early treatment in the line often recovered, for the battalion was rarely notified of a death.

Early rest, with saline and morphia, is highly desirable in giving the omentum and peritoneum some chance to carry on their protective work.

On reaching the casualty clearing station, abdominal cases should be put to bed with as little delay as possible, and after a preliminary examination it is wise to wait three or four hours. This will give the surgeon an opportunity of finding out which way the case is going, and at the same time it gives the wounded man a rest after the motor journey. Should the pulse-rate increase, vomiting of a persistent type set in or continue, and be associated with abdominal rigidity and tenderness, then operation should not be delayed. If, on the other hand, there is little vomiting and the pulse-rate remains at what it was on admission, it is better to wait.

If the missile is still in, and especially if its position is suspected to be retroperitoneal, an X-ray should be taken in order to guide the surgeon in his search for it. The early removal of the missile, especially shell, is most important, as a fatal infection is almost certain to ensue if it is left in the retroperitoneal tissues. We have in rare instances localised the missile in the abdominal cavity. A second X-ray has shown that it has changed its position, and after forty-eight hours it has been passed in the stool, and this without any symptoms of leakage from the gut.

Expectant Treatment.—If after two or three hours' rest in bed the pulse-rate has not increased, the patient has warmed up and become more comfortable, and specially if vomiting of a greenish-yellow material is not frequent or persistent, then it is quite justifiable to wait.

After a while the pulse-rate may fall and its quality improve. This is an indication that the intra-abdominal lesion is becoming localised.

Sips of water may be given by mouth, and this is aided by subcutaneous saline containing bicarbonate of soda. Bismuth carb. (gr. x.) is given three times a day, and tinct. camph. co. (♏xv.) combined with it seems to have a beneficial effect in these cases.

The abdominal wound should be dressed frequently with peroxide of hydrogen and hypochlorite solution, and a spreading infection should be carefully watched for. The temperature should be taken four-hourly.

These wounds do not usually give rise to serious infection. If, however, a spreading infection shows itself in the abdominal wall, it should be surgically dealt with without delay. At the end of forty-eight hours one of the following events may happen :

A. The pulse-rate may have fallen and its quality improved. The presence of a definite localised tender area may be present. There may be a little distension, with cessation of vomiting. The patient may have passed urine and perhaps some flatus.

B. The pulse-rate may be rising after a temporary fall, and distension with persistent vomiting of an obstructive type may have set in.

Should the second of these conditions obtain, and it is apt to set in very rapidly, then operation should be performed without delay.

Three types of vomiting associated with abdominal injuries call for comment :

A. Vomiting on admission and aggravated by motor transport. The vomiting may be persistent, or it may diminish and cease entirely. The cause is reflex, and it has invariably denoted severe peritoneal irritation, by the products of extravasation from a hollow viscus. Should it cease with rest in bed, the damage done is probably being adequately dealt with by the omentum and peritoneum. Should it persist, our cases have shown extravasation on a large scale such as would be caused by a severe rupture of the small intestine while digestion was in active progress, rupture of the urinary bladder, and the like. Persistent early vomiting is a grave sign, and calls for early operative treatment.

B. Vomiting which has ceased and commences anew after forty-eight hours is generally obstructive, and the obstruction can be traced to one of the two following causes—

(1) Obstruction in the large gut, due to the presence of hard scybalæ.

(2) Obstruction, owing to plastic peritonitic adhesions resulting from the injury.

The first-named (A) is by far the more frequent, but we have seen both. Vomiting Class B is associated with distension, and so differs from Class A. Without operation we have seen men suffering from obstructive vomiting develop a fæcal fistula, which has saved the surgeon the task of interfering, and at the same time has perhaps saved the patient. Obstructive vomiting, if a fistula does not develop, calls for active interference, but the lesion is at this stage shut off and the outlook is better.

C. Vomiting which is not peritonitic, and where no excessive distension exists, is toxic, and denotes grave infection in the wound or wounds, especially if one be retroperitoneal. Vomiting associated with gas gangrene is well known and easily recognised, and is an extremely grave complication.

On the third day an enema is given ; the ordinary turpentine enema has proved the most serviceable. Great perseverance is needed on the part of the sister, as the rectum and gut are usually blocked with hard scybalous masses. Sometimes after administration of an enema a fæcal fistula has developed.

Scybalæ in this connection are perhaps the greatest bugbear to the surgeon. In the majority of cases scybalæ in great part have been the cause of obstruction following operation, far more often indeed than plastic peritonitis, and by obstruction they have been the cause of fæcal fistulæ.

Difficulty in getting the bowels to move after operation is well known to surgeons at the casualty clearing stations. When once the bowels have moved and the scybalæ have been evacuated, the danger as a rule is passed.

Obstruction setting in at the end of forty-eight hours has almost invariably occurred *below the site of injury in the small gut*, and has been traced to a large accumulation of scybalæ in the large gut. In only two cases did we see obstruction due to plastic peritonitis.

Some surgeons have prescribed calomel, pituitrin, etc., soon after operation, and fæcal fistulæ have sometimes followed their administration, again tending to prove that the obstruction is lower down; consequently the bowel gives at its weakest point—namely, at the site of the original injury.

Retroperitoneal wounds accompanied by paralytic distension of the gut respond well to pituitrin and calomel. In two cases fæcal fistulæ developed and discharged through the wounds. The fistulæ followed the administration of a turpentine enema. Both cases were well, and went to the base passing fæces both by fistula and rectum, the amount passing by the fistula steadily decreasing.

It is very important in the case of retroperitoneal wounds to extract the missile, which is often high explosive with its concomitant piece of clothing, and to evacuate the blood-clot as soon after injury as possible. Of course, a retroperitoneal hæmatoma and a penetration of the peritoneal cavity may coexist.

Operative Treatment—*The Operating-Theatre*.—The operating-theatre has been either a dug-out, a marquee, or a hut. The type of theatre in which we did most of our abdominal work was a wooden hut. The hut was plain and unpainted; it contained five operating-tables, side windows, but no skylight. After dark it was lighted by means of acetylene. This was the scheme adopted at a casualty clearing station in France.

At a base hospital in the Balkans the hut was divided into two separate theatres. One of these was reserved entirely for civilian surgery, and in it only operations such as the radical cure of hernia, removal of appendix, removal of internal semilunar cartilage, and the like, were undertaken. This theatre, the smaller of the two, was fully equipped, so that there was no interchange of instruments. The larger theatre accommodated four operating-tables of the service pattern, and was reserved entirely for the surgical treatment of wounds.

All sterilising was done in a sterilising-room containing three high-pressure sterilisers. An anæsthetic-room, linen-room, entrance-hall, and an annexe containing a boiler for providing hot water, completed the instillation. Skylights and side windows provided excellent lighting, and at night electric light was available.

Unfortunately, the theatre was not dust-proof, and no operations

except those of extreme urgency could be carried out when a Vardar wind was blowing.

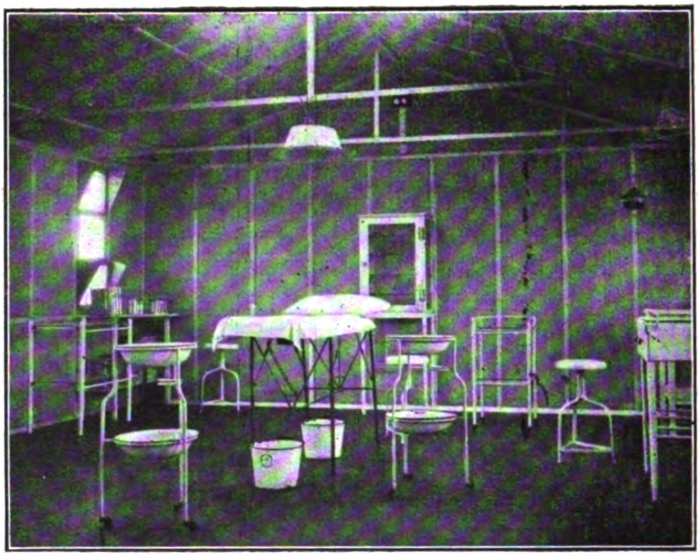

Fig. 333.—Operating-theatre for clean civilian surgery.

Fig. 334.—Operating-theatre for treatment of wounds.

Splints, surplus dressings, etc., were kept in a medical store close at hand.

During the hot season, surgeon, assistant, anæsthetist, and theatre staff, removed all their clothes and substituted sterilised suits made of

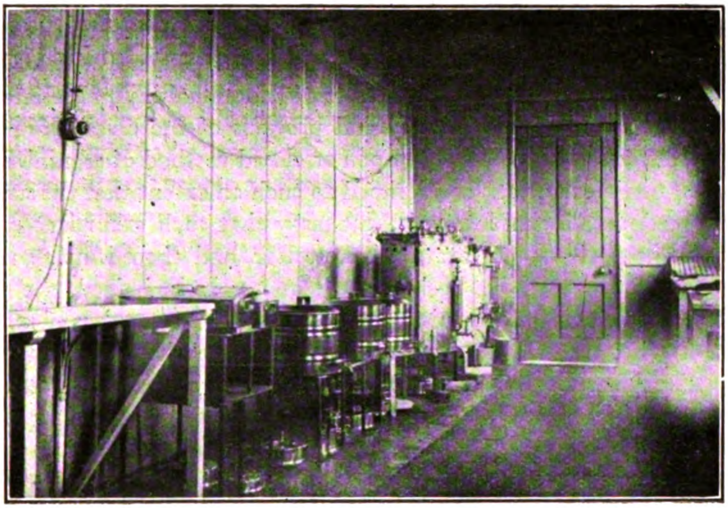

FIG. 335.—Sterilising-room.

FIG. 336.—View of part of medical store.

butter muslin. Over this was worn a sterile jaconet apron, and outside all a sterilised white gown. Even in this clothing the heat was very severe and trying.

Anæsthetic.—At the casualty clearing station in France the anæsthetic was chloroform, followed by ether, and whenever possible a preliminary dose of morphia (gr. $\frac{1}{4}$) and atropine (gr. $\frac{1}{100}$) was administered hypodermically. Ether was administered both by the open and closed method, but by far the most preferable from every point of view was its administration by the endotracheal method. Captain L. Game, R.A.M.C., gave endotracheal ether in a number of cases of abdominal injury for one of us, and, judging by the after-history and progress of the cases, the method proved far superior to either the open or closed method of administration. Diaphragmatic excursions are damped to such an extent that the surgeon's task is made much simpler, and the energy that such excursions entail is saved to the patient. Relaxation is complete, and there is no cyanosis or collection of mucus in the back of the throat. It is, indeed, the perfect anæsthetic for abdominal work, both from the surgeon's and patient's point of view, and perhaps from the point of view of the anæsthetist.

In the East, where dust-storms abound, ether anæsthesia is sometimes followed by a bronchitis which rather complicates the after-progress of a laparotomy. It is always advisable under these circumstances to give the anæsthetic warm.

Intravenous administration of ether in very collapsed cases is probably the best, for it is also a stimulant and it does much to combat shock.

Preparation of the Patient.—After arrival at the casualty clearing station the patient should be put to bed, made thoroughly warm, and given 2 pints of normal saline to which four teaspoonfuls of sodium bicarbonate and 1 ounce of brandy have been added. This is given subcutaneously. This preliminary is most essential, and markedly improves the condition of the patient prior to operation. It is probable that the bicarbonate neutralises the acid products of fatigue, the brandy acts as a stimulant on the circulation, so aiding their rapid removal, while the saline acts as a diluent and an aid to excretion. This mixture in all serious cases of wounds has proved, after extensive trial, to be far preferable to saline alone. At the same time morphia (gr. $\frac{1}{4}$) is given hypodermically if necessary. At the end of three or four hours it will usually be found that the general condition of the patient has very materially improved. He is now taken to the operating-theatre. The operating-table should be warmed by an apparatus, if provided, or by hot-water bottles, and great care must be taken in this connection not to burn the patient. All necessary shaving and preparation of the skin can be carried out while the anæsthesia is being induced ; it should not be done in the ward or marquee, as this involves an exposure which does more harm than good, and further distresses the patient.

Intraperitoneal Hæmorrhage.—Most cases of abdominal wounds complicated by severe intraperitoneal hæmorrhage die shortly after their arrival at the casualty clearing station, if indeed they survive the journey. Little success, if any, attends a laparotomy at this stage ; consequently, the operative treatment of such a condition will not be discussed here. We

would only suggest that if operation is to be of any use in this fatal class of case, then it must be performed far nearer the firing-line than either the casualty clearing station or the field ambulance. We mentioned

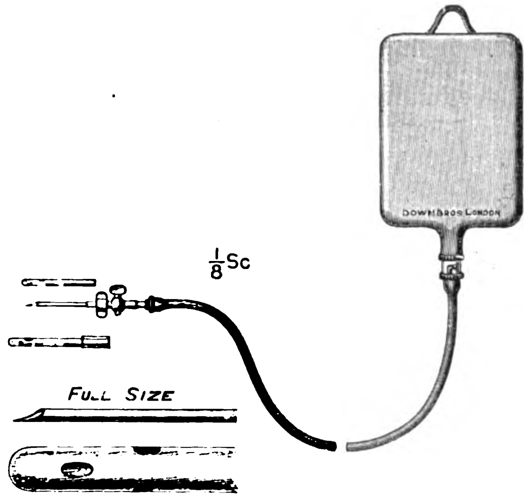

FIG. 337.—Apparatus for continuous saline infusion.
Suggested by Sir Wm. Arbuthnot Lane, M.S., etc.

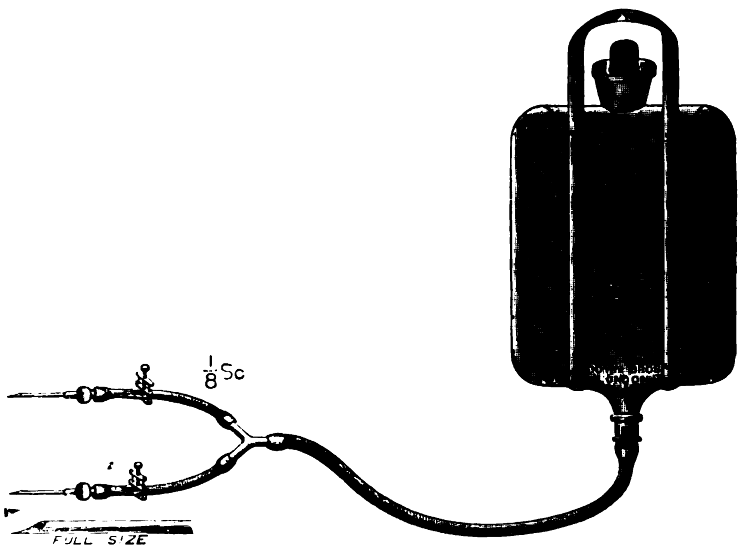

FIG. 338.

The more recent form, with double effluent, fitted with six-pint bag, as supplied to the War Office, and generally used in hospitals.

before that we had the opportunity of operating upon six cases in the lines; but we never made a practice of operating upon them at the casualty clearing station, for the results were both hopeless and disheartening-

ing, and the time taken over the operation, which rather hastened the end, was more profitably spent in dealing with cases that were more likely to benefit.

Wounded men suffering from intra-abdominal hæmorrhage must be put to bed without delay, and every effort made to rally them before undertaking operation. It was during this interval that so many of them died, and the futility of an operation in such cases was obvious.

Penetrating and Perforating Abdominal Wounds not complicated by Intraperitoneal Hæmorrhage.—In addition to the abdominal wound the surgeon has to reckon with fatigue, shock, mental complications, and other wounds elsewhere, which so frequently accompany an abdominal injury. We have frequently operated upon men with penetrating abdominal

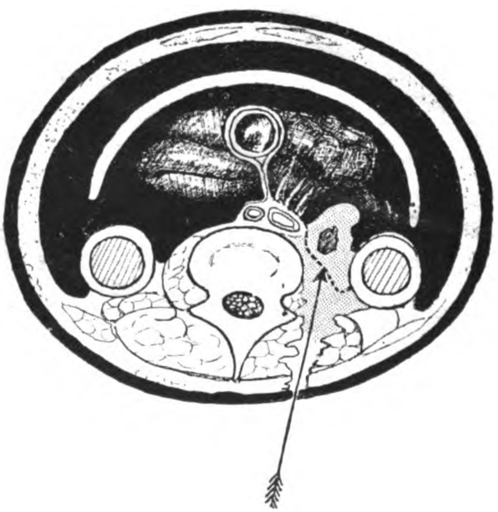

FIG. 339.—Diagrammatic representation of a penetrating wound of the back. Note the retroperitoneal hæmatoma marked in stipple pushing forwards the peritoneum, the original position of which is shown by the dotted line. The missile is lying within the blood-clot.

injuries who have in addition other complications such as a penetrating wound of the skull, gas gangrene of one of the extremities, compound fracture of bone, and the like. If such exist, then the surgeon has further to allow for a degree of bacterial toxæmia and added shock.

Operation.—The operation must be carried out as quickly, gently, and deftly as possible, and in most of our cases the actual time varied from twenty minutes to half an hour. Prolonged operations under these circumstances are very badly borne, and any additional shock must be avoided.

A further pint of normal saline solution containing two teaspoonfuls of sodium bicarbonate and ½ ounce of brandy is slowly run into the subcutaneous tissues of the axilla during operation. We have always used Lane's bag for the administration of the saline (see Figs. 337, 338).

The abdomen is shaved, cleansed well with ether, and painted with

iodine (dry preparation). The incision is determined by the area of maximum tenderness, and if possible is made paramedial.

On opening the peritoneal cavity the first point the surgeon looks for is escape of gas or bowel contents. Before the peritoneum is incised, its external appearance may be dark in colour, denoting some degree of intraperitoneal hæmorrhage. All extravasated material and blood should be removed with gauze mops, and a systematic examination of the gut carried out. The small intestine should be quickly examined in its entirety, looking both for damage to gut and damage to mesentery. This examination is carried out quickest and with least shock by starting at the ileocæcal junction. As each loop of small gut is examined by the surgeon, his assistant immediately returns it, if sound, to the peritoneal cavity. By this means exposure of the gut is reduced to a minimum.

FIG. 340.—Drawing of a perforation of the small intestine caused by a shrapnel ball. Note the pouting of the mucous membrane.

As each perforation is met, it is immediately sutured with two layers of fine thread.

When the small intestine has been examined and repaired, the surgeon next turns his attention to the large gut, and, starting at the cæcum, proceeds to examine the whole of the colon. Any perforations are repaired in just the same way as in the small gut. If necessary, the stomach (especially in cases of wounds involving the chest), the liver, and spleen must be examined, and any necessary repairs carried out.

At the same time a search for the missile should be made, and this is most frequently found either—

(1) In the lumen of the gut.
(2) In the bottom of the recto-vesical pouch.
(3) Wrapped up in the great omentum.
(4) In the abdominal wall.

This done, the peritoneal pouches are cleaned out and mopped dry. In nearly all our cases we have inserted a drainage-tube both to the damaged viscus and a smaller one to the pre-rectal pouch. We have never drained the flanks. The abdomen is now closed with through-and-through sutures

of silkworm-gut, and 2 to 3 ounces of warm ether are introduced into the peritoneal cavity through the tube leading to the pre-rectal pouch. The tube should then be clamped with a pair of Spencer Wells forceps, and these should be removed three hours later. The removal of the forceps is often followed by a gush of blood-stained fluid from the tube.

Dry dressings and a many-tailed bandage complete the operation, and the patient is immediately returned to a warm bed with plenty of hot-water bottles.

It may happen that when the abdomen is opened there is no escape of gas, blood, or extravasated products of the gut. The peritoneum clothing the gut may not be inflamed—in fact, no sign of local or general peritonitis may be apparent, although the gut may be distended. If such a state of affairs be met with, it is not necessary to explore the gut from end to end, for the cause of the condition is usually staring the surgeon in the face—viz., a retroperitoneal hæmatoma.

FIG. 341.—Diagram to show a penetrating wound of the back, causing severe damage to the left kidney.

Any surgeon who has handled many of these cases knows almost instinctively when the gut has been damaged. An inflamed, unpolished condition of the serous coat is almost pathognomonic of an injured hollow viscus, and in these circumstances the gut must be investigated.

Again, the peritonitis may be localised, and if this is the case, only that portion of the gut within this area calls for examination.

We have seen cases in which the peritonitis has been entirely limited to one half of the peritoneal cavity, the remaining half being shut off, and, again, cases have occurred in which only one of the abdominal quadrants has been involved.

It may happen that the gut has escaped injury, yet one flank may be full of blood, due to a damaged kidney, spleen, or liver.

The amount of work required inside the abdomen varies enormously,

and every case must be dealt with as occasion demands. Excessive handling must, however, be avoided, for not only does it increase shock, but it tends to the spread of peritonitis in cases where this latter condition has become localised.

Where early peritonitis is general, then the whole gut must be examined in a quick methodical manner.

What has been said so far applies generally to cases of penetrating abdominal wounds. The wounds of entry and exit, if the last named be present, must be excised, and often primary suture after excision can here be practised.

Operative Treatment of Special Conditions.

A. **Wounds of the Abdominal Wall with Non-Perforated Prolapsed Gut.**—After shaving and thoroughly cleansing the skin of the abdominal wall, the wound to the extent of ¼ inch around the prolapsed gut is carefully excised, care being taken not to touch the peritoneum. It is rare to find the peritoneal cavity infected when such a condition exists, for the prolapsed gut and omentum act like a cork, the serous coat of the prolapsed gut becoming sealed to the rent in the peritoneum by exudate. While the excised wound is carefully protected with a sterilised towel, the prolapsed gut is well washed with warm normal saline and returned to the abdominal cavity. Although the loop of gut has been soiled, little or no harm has resulted in returning it to the abdominal cavity. The abdominal wall is finally repaired and sutured.

B. **Wounds of the Abdominal Wall with Perforation of the Prolapsed Gut.**—After thoroughly cleansing the skin of the abdominal wall it may be possible to stitch up the perforation in the gut. Unfortunately, in most cases of this particular class of wound, the gut is so soiled and damaged that there is no other alternative but to resect the piece of prolapsed viscus and perform an end-to-end anastomosis. This part of the operation should be carried out after excision of the wound in the abdominal wall. Resection of damaged gut, the result of gunshot injury, followed by an end-to-end anastomosis, is a procedure attended with a high mortality; but if the perforated gut be prolapsed and the general peritoneal cavity not infected, which in this connection is usually the case, then the outlook is better.

C. **When the missile has penetrated the abdominal cavity and has not emerged,** there are three main points in treatment to consider:

(1) Excision of the wound in the abdominal parietes.
(2) Repair of any damage to the abdominal contents.
(3) Removal of the missile.

It is sometimes possible to include the wound of entry in the laparotomy incision; but if this is not feasible, it is better to excise the wound first, suture it, and paint over the suture with masticol varnish. This done, proceed with clean instruments to open the abdomen.

Repair of Damage to Gut.—Perforations of the gut may be either single or multiple.

Single Perforations have been found most frequently in the large intestine, the commonest sites being the cæcum, the hepatic flexure, the splenic flexure, and the descending colon. We have only in rare instances seen a single puncture of the small intestine. Perforations of the large intestine show a remarkable tendency to become isolated, and there is little doubt that a number would recover if left alone, a fæcal fistula resulting. When the abdomen has been opened, the perforations should be closed as quickly as possible with a double row of sutures, and this is often a difficult and trying task if the lesion be present in the hepatic or splenic flexures. A drainage-tube down to the perforation is advisable for forty-eight hours, for in some instances a fæcal fistula has developed after suture. After suture of the perforation we have been in the habit of stitching over the suture line an omental graft. Sometimes an omental graft has been sufficient in itself to close the breach in the gut, and we used it in two cases with success where the hepatic flexure of the colon had been punctured.

Multiple Perforations are seen in the small gut, and the choice of operation lies between—

(*a*) Suture of the separate perforations.
(*b*) Resection of the damaged gut, followed by an end-to-end or lateral anastomosis.
(*c*) Enterecto-enterostomy.

(*a*) Is undoubtedly the operation of choice, for it is quicker and occasions less shock. The perforations should be closed with a double row of thread sutures, preferably inserted in the long axis of the bowel. This done, we have surrounded this part of the bowel with a petticoat of omentum, securing the latter in position by means of one or two thin catgut sutures. It is a rapid procedure, and an additional safeguard against fistula.

(*b*) Is the operation called for when both bowel and mesentery, or the mesentery alone, have been damaged to such a degree that the blood-supply to the gut has been either cut off or severely interfered with. This operation in recently wounded men is a big undertaking, and is associated with a high mortality. It should therefore only be undertaken when course (*a*) is absolutely out of the question.

(*c*) Is called for only when the wounded man's condition will not warrant the undertaking of procedures (*a*) or (*b*). The operation can be undertaken rapidly, and involves much less handling. After the peritoneal cavity has become shut off, continuity of the proximal and distal limbs of the divided gut can be established by means of a Dupuytren's clamp.

Procedure (*b*) and (*c*) are carried out in exactly the same manner as they would be for civil diseases demanding them—*e.g.*, strangulated gangrenous bowel, malignant disease, and the like. The methods are described in textbooks, and call for no further comment here.

The Liver.—The liver may be damaged either as the result of a penetrating abdominal wound or of a contused wound of the anterior abdominal wall. Penetrating wounds of the liver are not, as a rule, serious, although in one case we extracted a piece of high explosive from this viscus, with a concomitant piece of clothing, and found gas present. The gas infection was limited, and the patient made a rapid and uninterrupted recovery. Contused wounds of the abdominal wall have been associated with most severe tearing of the liver and consequent intraperitoneal hæmorrhage. We have operated upon four cases, and on opening the abdomen, hæmorrhage was seen to be coming from large rents in the liver substance. The hæmorrhage was readily controlled by a finger in the foramen of Winslow, while the rent in the liver was repaired by stout mattress sutures of catgut. The abdomen was closed in three layers after clearing out all blood-clot from the peritoneal cavity, and all four cases made an uninterrupted recovery.

The Gall-Bladder.—Injuries of the gall-bladder are uncommon, and in all we have seen three, one the result of a rifle bullet, the other two the result of pieces of bomb. The rarity of the involvement of the gall-bladder in cases of penetrating abdominal wounds is perhaps explained by its protected position.

The case caused by a rifle bullet was that of Pte. ——, wounded on September 23, 1915. He was brought to the regimental aid post, where it was found necessary to detain him for forty-eight hours. He was hit over the gall-bladder area, and later his dressings became bile-stained. He complained of much pain and tenderness. A vertical incision was made through the wound of entry, and this was followed by a gush of bile, and with it the rifle bullet. A tube was inserted, and the man left the line comfortable. We can safely assume that he recovered, because his regiment was never informed of his death.

Of the other two cases, one was that of a German wounded in the right back by high explosive on the Somme in August, 1916. An incision was made through the right rectus above the umbilicus. Large quantities of bile escaped, the right renal pouch being full. The missile was found free in the right renal pouch. The gall-bladder was severely lacerated, and there was some laceration of the under surfaces of the right lobe of the liver. The right renal pouch was drained from behind. This man was very emaciated on admission, having lain out for forty-eight hours and having been without food for five days. He died on the sixth day after operation from asthenia, having gone to skin and bone.

The third case was that of Pte. ——, wounded in July, 1916. He was hit in the right upper abdominal quadrant, sustaining a perforation of the hepatic flexure of the colon and a wound of the gall-bladder. Operation performed twenty-two hours after injury showed the presence of a general and extensive peritonitis. The rent in the colon was sutured and chole-

cystectomy was performed. Death followed twenty-four hours later from general peritonitis.

Wounds of the gall-bladder, few as they have been, are of a very serious nature. If at the same time the intestine is injured, the outlook is still more serious, as bile exerts an inhibitory action on the natural resistance to infection of the peritoneum.

If the gall-bladder is very torn, cholecystectomy would seem to be the most suitable treatment. If, however, a small penetrating wound only be present, then either suture or cholecystostomy is the operation of choice.

The Pancreas.—Wounds of the pancreas are notoriously fatal. We can, however, quote one case of recovery. Captain K—— crashed to earth with his aeroplane in May, 1917. He sustained a severe scalp wound with a compound fracture of the calvarium, a compound fracture of his left tibia and fibula, and he complained of abdominal pain. Forty-eight hours after the accident he commenced to vomit a coffee-ground material; associated with this was rigidity and tenderness in the epigastrium. Persistent vomiting and increased pain were present at the end of the next twenty-four hours, and laparotomy was performed. The incision was medial and above the umbilicus. Contusion of the muscles of the anterior abdominal wall was present, and when the peritoneum was opened a flaky fluid escaped. A search revealed a large tear of the head of the pancreas, from which a sanious fluid was oozing. There was no fat necrosis in the mesentery. The rent in the pancreas was sutured with fine thread, and an omental graft was stitched over the line of suture. A tube was inserted down to the wound in the viscus, and the laparotomy incision was closed in three layers. A quantity of alkaline fluid escaped from the tube for five or six days following operation. The skin of the anterior abdominal wall did not suffer, as it was protected with sterilised carbolised vaselin. The patient made a good recovery, and was taking his food well and had put on weight when he left hospital three months later.

We saw seven cases of gunshot injuries of the pancreas at the casualty clearing station. Laparotomy was performed and drainage established, but not one recovered.

The Spleen.—Gunshot injuries of the spleen are usually associated with severe hæmorrhage. The spleen may be simply perforated, or on the other hand, it may be pulped. The latter was the condition seen in two cases operated upon by one of us in the line.

The only satisfactory treatment of wounds of the spleen associated with hæmorrhage is splenectomy. This operation was performed by one of us in three cases, all of which recovered.

The Kidney.—Wounds of the kidneys are not uncommon, and vary much in extent. A contused wound of the loin will frequently give rise to hæmaturia. A perforated wound of the loin involving the kidney (usually the lower lobe) may cause slight damage, or the kidney may be pulped. When the kidney is badly damaged, severe hæmorrhage may

result. The whole question of treatment depends upon the amount of damage inflicted on the kidney substance, the ureter and renal vessels. Thus, if a piece of the kidney still remains attached to an intact ureter and renal artery, and this has often happened, it is best to remove the detached portion and leave the attached portion behind.

If the damaged kidney be severely lacerated, but still attached to an intact ureter and renal vessels, it is far preferable to suture the lacerations and leave the kidney behind. If, however, the kidney be pulped, and severe hæmorrhage has taken place from damaged renal vessels, then nephrectomy is the only course.

The damaged kidney should be freely exposed after excision of the wound of entry. After the blood-clot has been turned out and any necessary repairs to the kidney completed, the wound should be stitched up and one or two Carrel's tubes included, into which hypochlorite solution can be instilled six-hourly. It may happen that the missile, after damaging the kidney, has gone on and entered the peritoneal cavity, causing further damage to the abdominal viscera. If this be the case, the wound in the peritoneum should be closed, through the incision planned for exploring the kidney, prior to performing laparotomy for the investigation of further damage in the peritoneal cavity. A wounded kidney gives rise to hæmaturia for a day or two, and a urinary fistula may develop in the wound. This usually closes in time without further operation. It is striking how much damage a kidney can stand and yet recover its function.

The Ureter.—The ureter is not uncommonly damaged in penetrating abdominal wounds, especially if the point of entry is in the lower loin or upper buttock. We have been concerned with ten of these cases. Of these, seven were complicated by injury of the intestine, and out of the total number seven recovered. Often a damaged ureter is complicated by a compound fracture of the bony pelvis. The injury results in a urinary fistula, with a transient and slight hæmaturia.

Immediate or late operations for wounds of the ureter have not done well, and it is far better to wait for the fistula to close. This happened in all our seven cases that recovered, the length of time for closure varying from three weeks to four months.

During the healing of a urinary fistula, the result of a damaged ureter, intervals of time exist in which no urine comes from the fistula at all. Thus, no urine may come from the fistula at all for five, six, or ten days, and then suddenly the fistula may start discharging again, though not excessively, for forty-eight hours. Eventually the fistula heals soundly, and the patient seems none the worse.

In two of our cases the urinary fistula closed, although the ureter was completely divided by the missile, and was never sutured. In one case the ureter was torn and contused, yet it recovered and functioned again without the help of the surgeon.

Certainly this war has taught us much about the genito-urinary tract.

We now know that both kidneys and ureters can stand a degree of mutilation never before thought of, and yet, if left alone, can recover and function anew. One well remembers in the pre-war period nephrectomy being performed for far less damage to a kidney than has obtained in many cases in the present war, and yet these latter cases have recovered and done well without nephrectomy. We think the lesson this has taught should make surgeons far more conservative in the matter of renal surgery after the war.

The Urinary Bladder.—Wounds of the urinary bladder are accompanied by extravasation. In most cases extravasation has been intraperitoneal. Symptoms are typical. There is severe pain with inability to pass water, the pain being referred to the groins, penis, and sometimes the scrotum. A catheter, when passed, usually draws off a small quantity of blood-stained urine.

Prior to a medial subumbilical laparotomy a catheter is first passed into the bladder *per urethram*, and tied in. Laparotomy is then performed, and all extravasated urine is mopped out from the prerectal pouch and the remainder of the peritoneal cavity. The rent in the bladder is sutured with catgut (one row of sutures), and over the suture-line an omental graft is stitched. A tube is inserted into the prerectal pouch and the abdominal wall closed. The catheter is removed at the end of forty-eight hours, and the tube in the prerectal pouch at the end of the third day. Bladder wounds have done remarkably well, and urine has been voided without trouble after the third day. Urotropine (gr. x.) has been given by mouth three times a day, and no complications have followed. Bladder injuries appear to heal rapidly and soundly.

The Rectum.—Wounds of the rectum and anus are difficult to treat and to keep clean. If the intraperitoneal portion of the rectum be involved, then laparotomy must be performed, and the rent sutured in the same way that has been recommended already for any other damaged hollow viscus. If, however, the extraperitoneal portion of the rectum be damaged, and the lesion, as it often is, associated with compound fracture of the bony pelvis, then left inguinal colotomy, with frequent lavage of the distal portion of the gut with the hypochlorites, has given excellent results. If the fæcal current be not diverted from the original wound, septic and even fatal complications are very prone to follow. The colotomy can always be closed at a later date.

Suture of Perforations of the Intestine.—A perforated wound of the intestine is generally associated with pouting of the intestinal mucosa. Some surgeons have advised clipping away the redundant mucosa prior to suture. This course only lengthens the operation, and we have not found it necessary. We use one continuous suture of thread including all coats of the bowel, and a second continuous suture including only the sero-muscular coat, the latter suture burying the former. Over the second suture-line we have fixed an omental graft with one or two single sutures of thin catgut. This has in our experience proved

the quickest method, and has in every way given highly satisfactory results.

The Peritoneum.—All extravasated matter must be gently and thoroughly mopped up with dry gauze. We have not practised peritoneal lavage, and do not recommend it. One large rubber tube has been placed in the prerectal pouch or the kidney pouch, whichever the case demanded; a second tube has been inserted down to the damaged part of the gut. After closure of the abdominal wall 2 to 3 ounces of ether have been left in the peritoneal cavity, and we can attribute benefit to its use, for it combats shock, it prolongs post-operative sleep, and it prevents to some degree post-operative intestinal inertia. The missile, if possible, should always be removed from the peritoneal cavity.

Closure of the Abdominal Wall.—The method of closure of the abdominal wall will depend upon whether the wound is anterior or posterior. If the wound is situate in the posterior abdominal wall, the necessary abdominal exploration is preferably conducted through a laparotomy incision in the anterior abdominal wall. This gives the surgeon the opportunity to close the rent in the posterior peritoneum. We have always done this with a running suture of catgut. This done, the wound in the back can either be left open or sutured, after excision. Whichever course be adopted, one or more Carrel's tubes should be included in the open or closed wound. The laparotomy incision may be closed either in three layers or with through sutures of silkworm-gut. We have tried both methods, and prefer the latter. It has been our experience that many laparotomy incisions which have been closed in three layers have suppurated, and in one or two gas gangrene supervened. By using through-and-through sutures of silkworm-gut, infection in the wound is far less frequent and severe, the time taken to close the laparotomy incision is shorter, and the end-results are as good. Further, as there is usually much vomiting following operation, the laparotomy wound is far less liable to give way when through-and-through sutures have been used.

Laparotomy incisions for gunshot wounds of the abdomen, whatever care be taken, are very prone to infection. This is probably explained by—

(1) The temporary diminished resistance to infection which most wounded men possess.
(2) The wound from the beginning is often septic.
(3) Extravasation of intestinal contents into the peritoneal cavity, has often taken place.

Laparotomy incisions are most frequently infected by staphylococci streptococci, and *B. coli.* They are not exempt, however, from gas-gangrene infection, and this grave complication, when it occurs, sets in with alarming rapidity.

When tubes have been included in the peritoneal cavity, and the abdominal wall closed by through-and-through sutures of fishing gut, we have

not seen this last-named complication occur. Some surgeons say that infection of the laparotomy incision is due to errors in technique, but those with experience at a casualty clearing station will agree that these cases differ from anything of the kind met with in civilian practice. At the casualty clearing station on several occasions, during a rush, laparotomy for acute appendicitis has been performed in the same theatre and under the same conditions as laparotomy for gunshot wounds, yet the former cases have in most instances healed *per primam*. The reason is that there are *fatigue*, *shock*, and *infection* to reckon with in abdominal gunshot wounds, and often *serious wounds elsewhere*. Despite the best efforts, the men who survive these injuries and the necessary laparotomy usually leave the clearing station with a skin wound that is still open and granulating. In a few of our later cases we have included two Carrel's tubes in the closed laparotomy wound, and have instilled a drachm of hypochlorite into each six-hourly. The result in ten consecutive cases has been healing *per primam* in seven and slight gaping only of the skin in three.

After-Treatment.—The first three days following operation are the most difficult and critical. The operation, however skilfully and rapidly performed, is only the first step towards a successful issue. Just as important is the after-treatment, and we ascribe the greater share of the credit of success to the nursing staff who looked after and were most untiring in their care of our cases.

Wounds complicating an abdominal injury require dressings which call for special care and skill. They may be of a grave description, such as compound fracture of bone, penetrating wounds of the head or chest, or large infected flesh wounds.

Men with abdominal wounds are often extremely restless, and require unlimited patience. The most constant post-operative complications calling for immediate attention are—

(1) Persistent biliary vomiting.
(2) Post-operative inertia of the gut with abdominal distension.

Persistent Biliary Vomiting.—Stomach lavage is by far the most satisfactory treatment of post-operative vomiting. We have used for this a warm watery solution of bicarbonate of soda (ʒi. to the pint). Lavage should be carried out twice daily until the vomiting ceases.

If stomach lavage is too distressing to the patient, which is rarely the case, then large drinks of water containing sodium bicarbonate can be given instead. Solid food in the form of dry biscuits, with sips of champagne, will often stop or profoundly modify the vomiting.

The nature of the vomit is important. The colour is at first yellowish-green, but subsequently varies. Should the yellowish-green colour persist after twenty-four hours, the outlook is serious; and should it persist after forty-eight hours, the outlook is grave. If after twenty-four hours

the colour of the vomit tends to get clear—that is, if there is less bile present—the outlook is good.

Should a green-coloured vomit persist after twenty-four or thirty-six hours, a subcutaneous or intravenous administration of saline containing two teaspoonfuls of sodium bicarbonate to the pint has in many cases either arrested or profoundly modified both the frequency and nature of the vomit.

Stomach lavage must be persevered with until the colour of the vomit begins to get lighter and less bile-stained.

Post-Operative Inertia of the Gut with Abdominal Distension.—Abdominal distension is due—

(1) To the handling of the viscera during operation.
(2) To a degree of obstruction caused by the presence of hard scybalæ in the large intestine.
(3) To a degree of peritonitis.

Paresis brought about by the handling of the gut soon passes off and requires no treatment. Obstruction caused by the presence of scybalæ is best treated with frequent turpentine and oil enemata, followed by a large wash out enema. High enemata should be aimed at, though this is not always possible owing to the rectum itself being blocked with hard fæces. On more than one occasion it has been necessary to clear the rectum digitally, a proceeding which is both painful and distressing to the patient. Perseverance with enemata has in the majority of instances sufficed to clear the bowel. Some surgeons, in order to prevent distension due to scybalæ, have performed an ileo-sigmoidostomy at the time of operating on the injured viscus. This procedure prolongs the operation only by a few minutes, but it undoubtedly increases shock. Further, the results gained in the few cases in which it was tried were not encouraging, and on the whole were not so good as those obtained by frequent enemata.

Paresis of the gut due to peritonitis responds well to subcutaneous injections of pituitrin (1 c.c., repeated if necessary), or hypodermic injections of eserine salicylate (gr. $\frac{1}{100}$) given hourly for three successive doses.

On the fourth day after operation castor oil (℥i.) may be given by mouth, and, providing the vomiting has ceased, the bowels usually move without trouble. Some surgeons prefer to give calomel in 1-grain doses hourly up to 5 grains. We have tried this in cases of gunshot injury, but finding that it griped the patient and caused him pain, we discontinued it.

Directly following operation, whether vomiting be present or not, we have given 10 grains of bismuth carbonate, together with 15 grains of sodium bicarbonate, in the form of a mixture three times a day. With this may be given tinct. camph. co. (♏xv.).

Complications during Convalescence other than Vomiting and Obstruction.—These are—

(1) Severe infection of the laparotomy wound.
(2) The formation of a fæcal fistula.

Severe Infection of the Laparotomy Wound.—This was at one time an almost unavoidable complication. Cases occurred in which gas gangrene appeared in the abdominal incision. Some surgeons who had met this complication, left the skin wound open and applied a salt pack as a prophylactic measure. We cannot speak of the results of this treatment. Since the inclusion of two Carrel's tubes in the sutured wound in later cases we have seen no further complications of this kind.

Formation of a Fæcal Fistula.—This is, unfortunately, by no means a rare complication. When once the fistula has formed, expectant treatment should be adopted. If the fistula involve the small intestine, the skin around must be carefully protected with carbolised vaselin in order to prevent excoriation. The wound must be constantly dressed and kept clean. If left alone fistulæ will often close by themselves, and this has happened in a number of cases which we have seen through to a finish at a base hospital.

Diet.—The early administration of solid food has done more good than harm, and seems to have a beneficial action in controlling the vomiting.

It is good practice to give the patients dry biscuits or toast with sips of champagne the day following operation.

Sweets, such as acid drops, do much to allay thirst and stimulate a flow of saliva. On the third day, eggs, fish, minced chicken, custard and milk puddings, can be given, and most patients can digest and enjoy this diet. The solid diet is gradually increased, and at the end of the seventh or eighth day more substantial diets are usually well tolerated and enjoyed. Patients at the end of this period are fit to be removed to the base.

Careful attention during the first two or three days following operation must be paid to the patient's mouth ; he should be encouraged to clean his teeth twice daily, and he should be shaved and have his hair cut short. Unshaven abdominal patients with long, unkempt hair are distressing-looking sights not only to their fellow-patients, but to those responsible for their care.

Treatment at the Base.—We can record fifty-five cases seen to the finish at a base hospital in the Balkans.

Abdominal wounds which have been operated upon at a clearing station have, on reaching the base, in the majority of instances, been open granulating wounds with a bacterial count of, on an average, 10 to 15 organisms per field. The patients have been comfortable and able to take and enjoy ordinary diet.

Some cases arrive in which the laparotomy incision is medial, others in which it is paramedial.

Granulating laparotomy wounds, on arrival at a base hospital, should be rendered sterile as soon as possible by the Carrel-Dakin or other methods. These wounds can be sterilised in eight days or less, and

secondary suture performed. The stitches may be removed at the end of the ninth day, and the patients allowed to get up.

The average time spent in bed for fifty-five cases, reckoned between the time of receiving their wounds and the time of getting up with the wounds healed, was twenty-six days. At the end of six weeks they were fit to go on a hospital ship, as they were able to walk and look after themselves.

After the end of the fifth week some of the patients complained of pain on micturition, others of constipation and painful collections of wind. These symptoms were doubtless due to early adhesions. Potassium iodide (gr. v.) with tincture of belladonna (♏ v.) was often all that was required to give relief.

Abdominal patients should be given a teaspoonful of paraffin night and morning. This dose was quite sufficient, for the tendency in the Balkans is towards diarrhœa rather than constipation.

The Abdominal Scar.—When paramedial incisions for laparotomy have been employed, the final scar was sound, and there was no tendency to hernia. This did not obtain, however, in the case of medial incisions. In nearly all the latter cases there was pronounced weakness of the scar, with herniation of the abdominal contents (ventral hernia). Thus it is, from the point of view of subsequent herniation with the formation of adhesions, far preferable to use a paramedial laparotomy incision whenever possible.

Statistics.—The following lists comprise a series of abdominal injuries operated upon by one of us at a casualty clearing station in France, and also a series of cases reaching a base hospital in the Balkans, some of which were operated upon at the casualty clearing station, the remainder being operated upon at the base.

We would state that of the series operated upon in France, moribund cases were left alone, because, with a continuous rush of wounded going on over three months, it seemed incorrect treatment to forfeit the lives of those who could be saved for the treatment of hopelessly moribund men. Further, we could see no point in complicating the last hours of these dying men with a futile laparotomy.

Of 52 cases of penetrating abdominal injury subjected to laparotomy at a casualty clearing station in France, 20 died, giving a recovery of 62 per cent.

Of the 20 cases which died, 9 were complicated by wounds of the thorax, 1 with a compound depressed fracture of the skull, 5 with compound fracture of the bones of the extremities or other large flesh wounds, and the remaining 5 were uncomplicated.

Of the 52 cases submitted to operation, 42 were concerned with penetration of hollow viscera, including the urinary and gall bladders and ureter; and of these 42 cases, 18 died, giving a recovery in the case of damage to hollow viscera of 58 per cent.

Of the remaining 10 cases submitted to operation, the kidney was damaged in 5, the liver in 2, the pancreas in 1, and in the remaining 2 cases the lesion was retroperitoneal. Of 6 cases operated upon in the line and not included in this list, recovery followed in 2, both cases having suffered hæmorrhage of a severe degree from a wounded spleen. The remaining 4 were concerned with extensive damage to the mesentery. We could include other urgent cases operated upon in the field ambulances in this list, but as they were only kept a very short time after operation, we cannot speak of their condition at the end of the eighth day, consequently we have not included them.

Of 55 laparotomy cases met with at a base hospital in the Balkans, 41 were operated upon at the casualty clearing stations and 14 at the base hospital.

Operations at Casualty Clearing Station, and reaching Base Hospital.

Penetration of large gut	5 cases (one case of resection and end-to-end anastomosis).
" " small gut	23 cases.
" " peritoneum and solid viscera (liver, kidney)	8 cases.
" " ureter	3 cases.
" " urinary bladder	2 cases.
	41 cases. No deaths at base.

Operations at Base Hospital.

			Deaths.		Recoveries.
Penetration of large gut	3 cases	...	1	...	2
Penetration of small gut (ureter 2 cases)...	9 cases	...	2	...	7
Rupture of pancreas	1 case	...	0	...	1
Peritoneum and ureter	1 case	...	1	...	0
			4		10

CHAPTER XXII

BURNS

Burns or scalds occurring in war-time are either accidental or the result of the explosion of a bomb or high-explosive shell in the immediate neighbourhood of the individual concerned. We did not see a single case of a burn result from the use of the Flammenwürfer (liquid fire).

Burns may vary in severity from a superficial erythema to most destructive charring.

The immediate complication of a burn is shock, and the degree will vary with the area of the body-surface involved. The remote complication is sepsis.

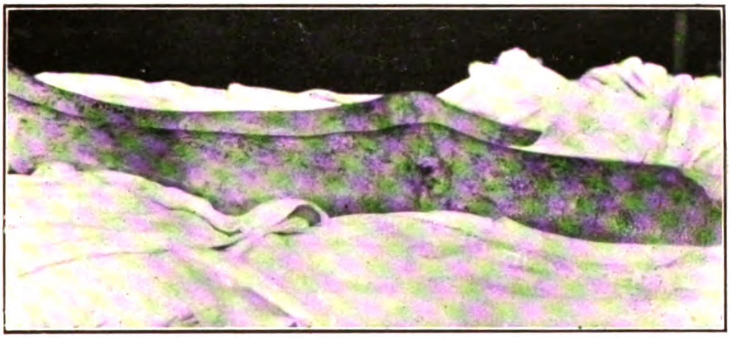

Fig. 342.—Extensive scalds of both legs the result of boiling fat. This patient died on the twelfth day following the accident from septic complications.

Eight cases of most severe burns involving considerably more than half the surface of the body, and all resulting from the same accident, were admitted to a base hospital. All the men were burned with cordite which had caught fire in a gun-pit. Five of the eight cases died, two from immediate shock, the remaining three from septic complications. The post-mortem findings in all those dying from septic absorption were the same. The liver, heart, and kidneys showed advanced fatty degeneration, both lungs were acutely congested, and in every case the stomach was dilated and the duodenum showed ulceration (see Fig. 343).

Treatment.

The burned areas should at once be protected from the air by means of sterile gauze, wool, and bandage. Brandy and other stimulants may be given, and the patient removed to hospital without delay.

On admission to hospital, he should be put to bed, made warm, and 2 pints of saline with 1 ounce of brandy should be given subcutaneously.

As soon as the pulse has improved, the patient is taken to the operating-theatre and anæsthetised with open ether. The burned areas are thoroughly washed with warmed normal saline solution and shaved. If the head and face have suffered they must be shaved. The quicker the burns are cleaned

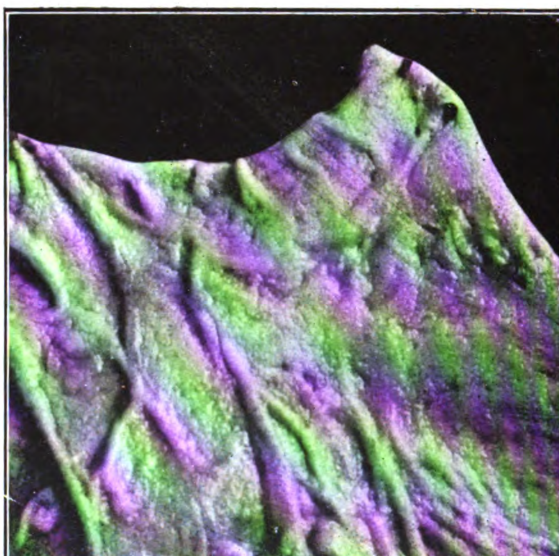

FIG. 343.—Ulcer of duodenum following a severe burn. Death on the tenth day from septic intoxication.

and dressed, the better the patient's chances; hence in the case of extensive burns two or more surgeons, if available, should work in conjunction.

Undoubtedly one of the best dressings for burns, if they can reach a hospital early, is Ambrine or its equivalent, Paraffin No. 7.

The burned areas, after shaving, are again carefully washed over with normal saline and dried prior to applying the dressing (see Fig. 344), with either a brush or a sprayer. We prefer the former.

Spray for the Treatment of Burns by Paraffin Wax.

The substance contained in this outfit is a mixture of paraffin and wax, etc. (Ambrine could also be used). It is solid when cold, and becomes fluid when heated to 140° to 150° F. It can be used as a "first-aid"

PLATE IX

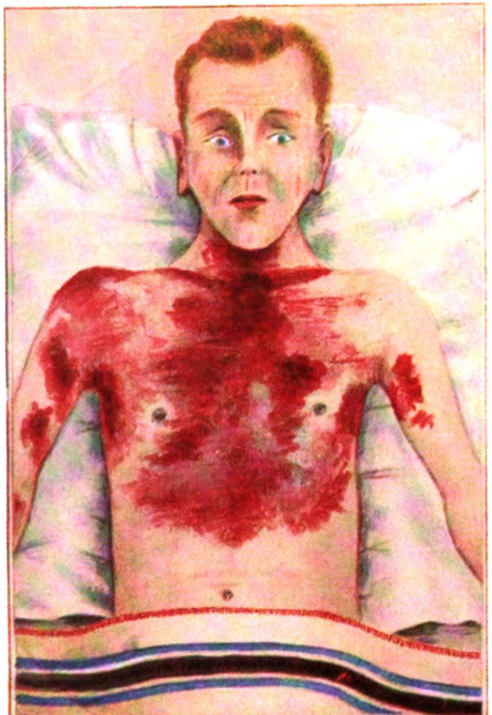

Fig. 1.

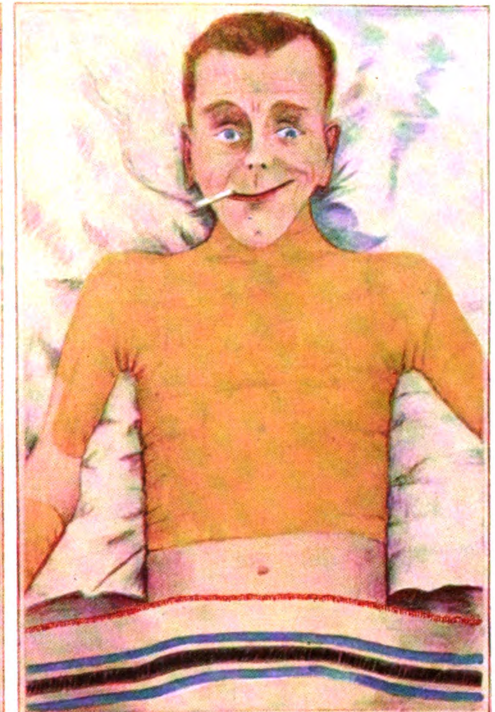

Fig. 2.

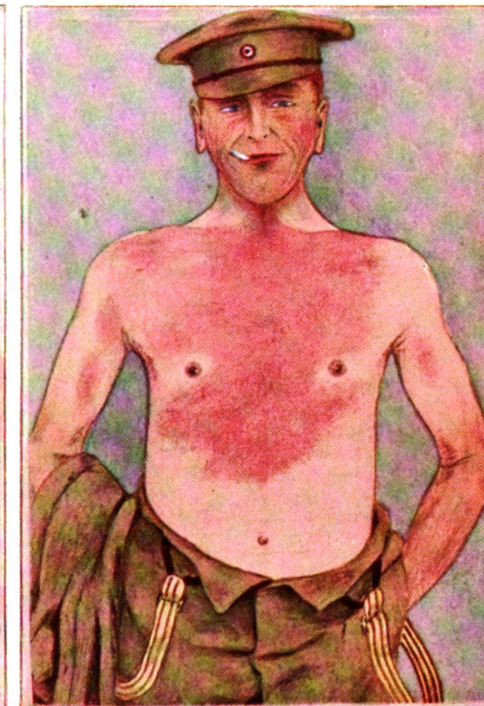

Fig. 3.

Figs. 1 and 2 show extensive burn before and after the dressing had been applied. The painting is taken from a patient whose shirt caught on fire, and represents very well the condition that existed.

Fig. 3. Same patient after healing of the burn.

To face page 570.

dressing for burns, and for their subsequent treatment, if considered desirable. The originator of this method (Dr. Barthe de Sandfort) advocates its use for all classes of burns and employs it through the whole stage of treatment, and he claims that by so doing he has had excellent results.

Methods of Use.

(A) Heating.—Place a piece of wax in the sprayer provided, and heat the latter over a spirit-lamp, or set it in a basin containing a little water, which should be kept boiling for ten minutes.

(B) Precautions to be taken.—Care should be taken to *prevent any water getting into the wax.* It must be remembered that the latter does not burn the tissues at 176° F., but the smallest quantity of water present would cause scalding. With the same end in view, the burnt area should

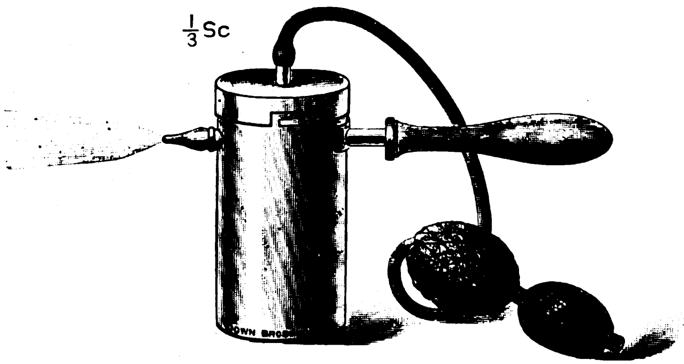

Fig. 344.—Spray for the treatment of burns by paraffin wax. Designed by Fleet-Surgeon D. W. Hewitt, F.R.C.S., R.N.

be gently dried before the application is made. While the wax is being heated, prepare a few fine layers of absorbent cotton ; these layers should be as thin as possible.

(C) The Dressing.—When the wax is in a liquid state and has been allowed to cool to a temperature of, roughly, from 140° to 150° F., it can then be applied to the burnt area, either by means of the spray or the brush supplied for the purpose, or by the sprayer followed by the brush. If the sprayer is used, the metal should be heated all over (including the nozzle), as any coagulation of the wax at this point will interfere with the proper working of the instrument.

The flame should be kept from the wooden handle and rubber bellows.

As regards the Technique.—The sprayer is first held about 9 inches from the patient, and the area is sprayed over until it has the appearance of being covered with a thin layer of hoar frost. The sprayer is now brought closer (say 3 to 4 inches), and the bellows briskly worked ; it will then be seen that in the centre of this spray-stream the wax assumes a liquid appearance. With this liquid spray the whole of the affected part

is now quickly covered. A thin layer of cotton-wool is next laid on this wax, and the whole is then again covered with the liquid wax by the brush. It is strongly recommended that the surgeon should first try the method by applying two or three dressings to his own hand and arm.

Note.—When removing the lid from the sprayer, do not hold it by the handle (as the leverage may buckle the side of the instrument). It should be held by the body of the sprayer, using a cloth if the metal is hot.

When using the Brush.—Remove the lid of the sprayer, take the brush provided, and dip it in the liquid. Now spread the latter over the wound without pressing—that is, as much as possible dabbing it, and not brushing it on; this operation is repeated until the glazing is complete, taking care to leave no spot uncovered. Immediately afterwards place quickly on this first wax glaze, one of the thin layers of absorbent cotton, already prepared as explained above, and then, with the same dabbing movement, put on several more applications of the fluid.

If the wound is extensive, the operation is done on small square surfaces successively and close together (about 4 by 4 inches). These little squares thus become part of one another.

After the preparation (which with cotton-wool forms a shell or casing) has been allowed to cool, dressings and bandages can be applied in the usual manner. The initial use of the sprayer is recommended where the area is painful.

Removing the Dressing.—For the first few days the waxen shell must not be left in place more than twenty-four hours; later, if it is decided to continue the use of wax, it can be left for forty-eight hours or even longer. To remove the dressing, untie the bandages and expose the "shell." An incision is made in the latter by means of a blunt knife or scissors, and the whole is peeled off. The wound is afterwards bathed with boiled water, and the cleansing is further perfected by washing with absorbent cotton soaked in boiled water. Then it is dried either by a current of warm air or by a piece of cotton-wool, care being taken not to rub or cause the granulations to bleed.

Antiseptic solutions should not be used (except very weak), and care should be taken not to apply the liquid at a temperature of more than 150° F.

Heating the wax in a bath of boiling water raises its temperature to nearly 212° F. Therefore, before applying it to the burn, *with a brush*, it should be removed from the water-bath and allowed to stand for a minute or two, so as to reduce its temperature to below 150° F.

It is claimed for the application that—

(1) It immediately alleviates pain.
(2) It constitutes a warm "shell" under which the tissues are protected against outside contamination.
(3) It can be removed without pain or injury to the newly forming tissues, and thus limits the formation of scar tissue.

If the burns are septic they should be cleaned and sterilised before the application of the paraffin dressing. The quickest and most satis-

FIG. 345.—Extensive burns of face treated with paraffin No. 7.

FIG. 346.—Extensive burns of hands in same patient as Fig. 345. This patient also suffered severe burns of both legs. Hands treated by Carrel-Dakin method.

factory method of bringing about sterilisation is by the application of a Carrel-Dakin dressing.

FIG. 347.—Other hand of same patient treated by Carrel-Dakin method.

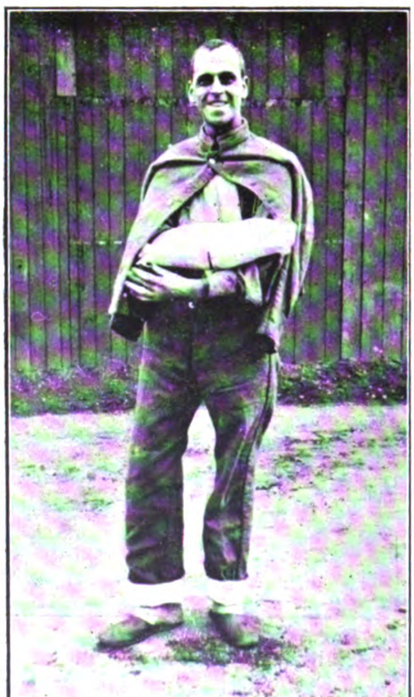

FIG. 348.—Same patient as in Fig. 345 five weeks after reception of burns. Both hands eventually recovered without scarring, and there is no scarring about the face.

After giving Paraffin No. 7 a considerable trial, we have arrived at the following conclusions :

(1) It is the best dressing that can be applied to burns if it is applied within an hour or two of the injury.
(2) The dressing is painless both in application and removal.
(3) The burned surface heals and skins over with remarkable rapidity.
(4) There is the minimum formation of scar tissue.
(5) It is useless to apply Paraffin No. 7 to septic surfaces. The surfaces must first be sterilised by the Carrel-Dakin method before the dressing is applied.

Should the skin be blistered and the blisters still unopened, they should be left and the preparation applied over them.

We do not recommend fomentations for cleaning up septic burns prior to applying Paraffin No. 7, for Carrel's treatment has given a quicker and more satisfactory sterilisation.

The treatment of gunshot wounds associated with burns has already been referred to. We have now abandoned the use of older remedies in the form of picric acid, carron oil, etc., for the results obtained by Paraffin No. 7 have entirely surpassed those obtained by the older methods.

CHAPTER XXIII

CONDITIONS PECULIAR TO AIRMEN

THERE are certain conditions peculiar to flying men which call for special notice. It has long been recognised that divers must descend to and ascend from the depths at which they work, gradually, in order that a state of equilibrium may become established between the increased pressure experienced in the depths and the normal atmospheric pressure.

A diver first passes from the normal to a higher atmospheric pressure. A state of equilibrium is soon brought about by a rise in the blood-pressure. His blood contains oxygen and carbon dioxide under a pressure proportionate to the increased pressure in his lungs. When he comes to the surface he leaves a higher atmospheric pressure to enter the normal. The latter change must be conducted slowly and gradually, otherwise alarming symptoms may follow. These symptoms constitute the condition known as Caisson Disease or Diver's Paralysis, and are described in most textbooks on medicine.

The changes brought about in an airman as the result of a transfer from a denser to a rarer medium are comparable to what is observed when a bottle of soda-water is opened. Air rapidly escapes, and continues to escape until a state of equilibrium is established.

An airman differs from a diver in that the conditions are reversed. The older flying machines climbed slowly ; consequently the change from dense to rare atmosphere was comparatively gradual. Aerial warfare has, however, necessitated alterations, and to-day the essentials of a good machine are speed and rapid climbing powers.

The present-day airman must therefore be an individual who can rapidly accommodate himself to sudden changes of pressure.

The changes brought about through the transfer from a denser to a rarer medium are mainly those concerning blood-pressure, though other important points have to be taken into consideration. Normally the atmospheric pressure acts directly upon all parts of the body to which it has immediate access—that is to say, skin and exposed mucous membranes, including the lungs. As the airman climbs, the atmospheric pressure decreases, while his internal pressure remains for the time being the same ; consequently the vessels of the skin and of the mucous membrane fill with blood, and whereas the intake of oxygen into the lungs is

less, the output of carbon dioxide for the time being is proportionately greater, consequently a temporary change in the respiratory quotient is brought about.

Turgidity of the mucous membrane gives rise to buzzing in the ears and deafness, the eyes become temporarily blurred, and hæmorrhage may occur from the ears, nose, and other mucous membranes. A diminished intake of oxygen may tend to drowsiness or a feeling of faintness. Such were the sensations experienced by one of us.

This state of things will continue until equilibrium is established. The more flying a man accomplishes, the sooner he can accommodate himself to a rapid change from a denser to a rarer medium ; in other words, he develops some sort of an immunity, if one may use the term, to a rapid change of conditions in pressure.

As the airman descends, he passes from a rarer to a denser medium. This change may be brought about slowly and at leisure, or it may have to take place rapidly if the flying man is wounded. On landing, the airman feels tired, and there is a strong tendency to sleep. After three or four hours' sleep he awakes refreshed, and there is a feeling of *bien être*.

Medical Examination of Men before entering the Royal Air Force.—No branch of the service calls for a more thorough medical examination of its officers and men than the Royal Air Force. An airman must possess good eyesight, his heart must be sound, he must not be subject to fits, and above all, he must be of a calm and composed disposition. Special attention must be directed towards an examination of the nose, lungs, and abdominal walls, and under no circumstances should a bleeder be admitted. Should unhealthy conditions of the nasal mucous membrane be present, such as hypertrophic rhinitis, nasal polypi, etc., these must be duly treated and put right before the man is allowed to fly. Should disease of the lung be present in the form of old tubercle which is quiescent, and especially if old cavitation exist, the man should be debarred, owing to the risk of hæmoptysis while flying in a rarefied medium. The abdominal wall should be most carefully examined for hernia or large patent external abdominal rings. On more than one occasion whilst flying a hernia has come down, owing to the absence of the normal atmospheric pressure which hitherto had been instrumental in keeping it up, and these herniæ are most prone to become strangulated. Any man desirous of entering the Royal Air Force must consent to an operation for the radical cure of his hernia or to an operation for the obliteration of a large patent abdominal ring through which a hernia, previously unrecognised, might readily descend. Varicose veins and hæmorrhoids must for obvious reasons be corrected.

Precautions to be taken by Flying Men.—No man should fly who possesses a breach of any sort in his skin, owing to the risk of hæmorrhage. The following cases may be quoted to illustrate this point :

Lieut. —— sustained a small accidental cut of his finger which bled slightly. He had a dressing applied, and as nothing further occurred,

he ascended in his machine on the following day. He felt a curious sensation in one of his gloves, and inspection showed that the glove was full of blood. He descended, and found that considerable hæmorrhage had occurred from the small cut in his finger.

Lieut. —— had a carious molar tooth extracted. Three days later he ascended in his machine, but was compelled to land owing to a profuse hæmorrhage from the tooth socket.

Wounds of Airmen.—The immediate danger of wounds inflicted on men whilst flying is uncontrollable and rapid hæmorrhage, this being due to the rarefied condition of the atmosphere. The extent of the hæmorrhage will vary with the length of time the man has been flying; thus, if an airman is hit soon after attaining a height, hæmorrhage will be severe, whereas if he is wounded after a state of equilibrium has been established between his blood-pressure and the rarefied atmosphere, then the hæmorrhage will be less severe. As he descends rapidly after being hit, he passes into a denser medium, and when he reaches normal atmospheric pressure the hæmorrhage often stops altogether.

Should the wound be at all extensive, another complication akin to surgical emphysema arises as he passes from a rarer into a denser atmosphere. Thus, we saw one case of a wounded airman who had been hit in the thigh. The thigh was tympanitic, the tissues being charged with air.

Curious as it may seem, an airman's wounds are frequently infected, and this can be explained only by the clothes. He may be wounded by shell or by machine-gun bullets from an enemy aeroplane. The latter bullets differ from those used by the German infantry in that they are of two kinds, armour-piercing and explosive.

It would seem that infection of wounds might be obviated in the case of airmen if by some means or other their clothes could be sterilised before a flight.

Treatment.—The actual treatment of airmen's wounds does not differ in any way from that employed for other wounded men. There are certain precautions, however, to be taken. When a wounded man lands he should have his wounds carefully dressed, and he should be kept quiet for at least two or three hours. There is a great risk in operating immediately upon a wounded airman before the necessary state of equilibrium has become established. After an interval of two or three hours of landing, he may safely be moved to a casualty clearing station, where his wounds can be surgically treated.

CHAPTER XXIV

WOUNDS OF THE ARTERIES AND PERIPHERAL NERVES

A WOUND involving an artery may result in contusion, perforation, or complete division of the vessel.

An artery may be contused as the result of a direct blow or through a fragment of a fractured bone being driven against it. The latter phenomenon is by no means uncommon in connection with fracture of the long bones.

Perforation is usually effected by small pieces of missile, usually bomb fragments. Perforation of an artery, the result of a rifle or machine-gun bullet, has been a rare event during the present war. The artery may be perforated in such a way that there is a separate wound of entry and exit in its walls, or the entry and exit wounds may be blended into one cavity. Complete division of an artery is usually the result of high explosive, and is but one part of a large lacerated wound. It occurs most frequently when a limb is either blown or torn away from the trunk. The artery may be either cleanly divided or a large piece of its continuity may be missing.

The vein may or may not be damaged, and the same applies to the nerve. Similarly, the nerve or vein may sustain injury, while the artery escapes.

A Contusion of an Artery may subside and the artery continue to function if it be put under the best conditions. Thus, if it forms part of a general contusion resulting from a blow which has not caused an open wound, then rest is all that is required. It may happen, however, that a contusion caused under these circumstances has resulted in severe damage to the artery wall, and consequently an aneurysm may follow in due course.

If the contusion is due to the presence of a missile or of a fractured bone which is driven against the artery wall, the missile must be removed at once and the fractured end of the bone drawn back into position.

Primary Hæmorrhage.—Should the artery be perforated or completely divided, primary hæmorrhage will result.

Primary hæmorrhage, as a rule, is not immediate if an artery is completely severed; on the other hand, it is immediate if the artery is buttonholed, for in the latter case the muscular coats of the artery as a whole can neither contract nor retract. The breach in the artery wall is therefore kept patent by a muscular contraction and retraction of the undamaged part of the artery wall, and hæmorrhage results.

Hæmorrhage may be either visible or concealed. Visible hæmorrhage occurs from open lacerated wounds or from larger penetrating wounds in which the damaged artery is fairly superficial. Concealed hæmorrhage occurs as the result of wounds involving closed cavities, such as the abdomen, thorax, and head. Concealed hæmorrhage, may, however, occur in such situations as the extremities and root of the neck. In the latter cases the hæmorrhage is usually the result of a very small missile; thus, it is not uncommon to see an acutely tense and swollen thigh or a tense swelling at the root of the neck giving rise to dyspnœa and dysphagia associated with an extremely minute wound of entry in the skin.

Primary hæmorrhage occasions shock and severely lowers the general resistance to infection; consequently wounds associated with primary hæmorrhage of a severe degree usually become grossly infected, and both septicæmia and secondary hæmorrhage are prone to follow. The wounds sterilise slowly and the patient is severely handicapped; hence the importance of arresting hæmorrhage at once.

Many cases of primary hæmorrhage, whether visible or concealed, are immediately fatal, and the patients die in the line.

Cases of concealed hæmorrhage occurring in such situations as the extremities or about the root of the neck vary as to their subsequent history. If the wounded part—take for instance the thigh—is put at rest and elevated, the swelling may subside and infection of the extravasated blood-clot may not follow. The skin becomes discoloured through the presence of changed blood, and there is usually little pain. Later the generalised swelling of the limb is replaced by a localised swelling, over which a bruit can be felt and heard; the localised swelling has a pulsating and expansile impulse—in other words, a traumatic aneurysm has formed.

Traumatic aneurysm is not infrequent, and the most common sites have been—

(1) The root of the neck (subclavian aneurysm).
(2) The axilla.
(3) The brachial artery at the junction of the middle and upper thirds of the upper arm.
(4) The femoral artery in its middle third.
(5) The popliteal artery.
(6) The intracranial portion of the internal carotid artery (two cases).

The nature of the aneurysm may be—

(*a*) Aneurysmal varix.
(*b*) Varicose aneurysm.
(*c*) False aneurysm.

Aneurysmal varix can occur only when both artery and vein have been wounded. The two perforations adhere, and a true direct com-

munication between artery and vein results. This type of aneurysm is rare.

Varicose aneurysm can occur only when both artery and vein have been injured, the communication between artery and vein in this case being established by means of a channel. This type of aneurysm, again, is rare in connection with war wounds.

By far the most common is the false aneurysm. This usually follows as the result of a small perforation of an artery. Blood escapes into the tissues, and the extent of the leak becomes limited and circumscribed. Around the circumscribed clot an envelope of fibrous tissue forms and a false sac results, which communicates with the breach in the artery. The formation of the sac may occur as early as forty-eight hours after injury, or it may be delayed as long as a fortnight. We saw one case at a casualty clearing station in which a pulsatile swelling had formed in the axilla thirty-six hours after injury, but those cases in which the popliteal, femoral, and brachial arteries were involved were only discernible on about the tenth to the fourteenth day.

Examples are the following :

Case 1.—Pte. S——, wounded on April 24, 1917, in the Balkans, was admitted to hospital with a swelling of the left side of his neck just below the lobule of the ear. There was a minute wound of entry over the swelling about twice the size of a large pin's head. He complained of difficulty in swallowing. On April 26 he coughed up a little blood, and with it a minute piece of high explosive (a fragment of a hand grenade). On April 28 his swallowing was easier, and he felt better and suffered less pain. On April 30 the swelling was subsiding, but he complained of buzzing noises in his head. On May 4—*i.e.*, ten days after injury—there was a circumscribed swelling below the lobule of the left ear about the size of a small tangerine orange, with a pulsatile impulse and a bruit to be felt over it.

Case 2.—Pte. —— was admitted to hospital in the Balkans on April 26, 1917, having sustained a wound of his left thigh. The thigh was acutely swollen and somewhat tender, and very small wounds of entry and exit were situated in its middle third. The circulation in the foot was good. The limb was immobilised and elevated. Four days later the swelling was subsiding, and the limb was yellow in colour owing to the presence of altered blood. On the ninth day following injury a pulsatile swelling appeared in the middle third of the thigh in the course of the superficial femoral artery as it lay in Hunter's canal.

Case 3.—Lieut. —— was admitted to a base hospital in the Balkans on the fourth day after receiving his wound. He had sustained a very small wound of entry at the root of the left side of his neck. On admission there was a diffuse swelling in the left infraclavicular fossa. The swelling subsided, and was replaced on the eleventh day by a pulsatile tumour.

CASE 4.—Pte. —— was wounded by a piece of high explosive which entered his right eye. The eye was destroyed and removed. On the

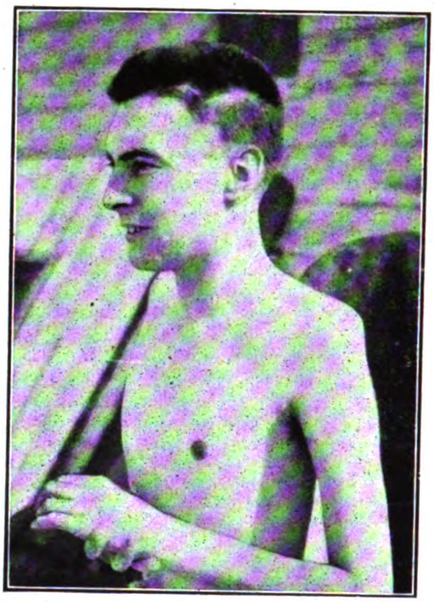

FIG. 349.—Aneurysm of left subclavian artery caused by small piece of missile entering the root of the left side of the neck.

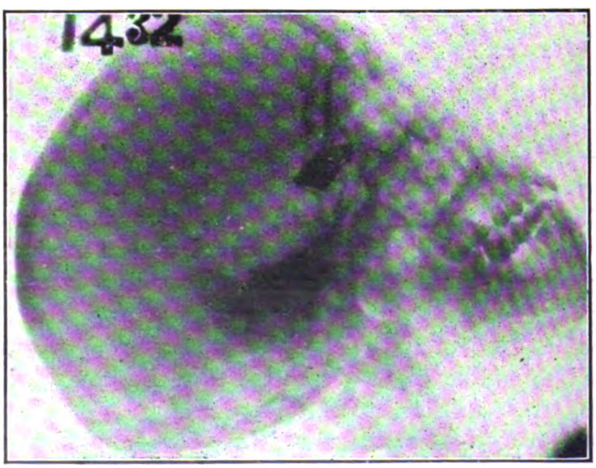

FIG. 350.—Aneurysm between cavernous sinus and intracranial portion of internal carotid artery, due to penetrating wound of right eye.

sixth day following injury he developed a pulsating exophthalmos of the sound eye.

Treatment.—The treatment of visible primary hæmorrhage should be its immediate arrest. Stretcher-bearers and combatants alike should be instructed how to arrest hæmorrhage. In the absence of the medical officer we adopted the following simple plan in the line, which worked very satisfactorily :

A puttee was tied around the limb above the hæmorrhage, and was screwed up tightly by means of a stick or entrenching-tool handle until hæmorrhage was arrested. The extemporised tourniquet was kept on until the medical officer arrived, when it was removed. The bleeding vessel was then picked up with Spencer Wells' forceps and ligatured. Cases in which hæmorrhage was concealed in such situations as the limbs or the root of the neck were treated by thorough immobilisation and elevation of the part, with a ¼ grain of morphia given hypodermically.

Treatment at the casualty clearing station should be that already recommended for lacerated wounds—namely, excision and sterilisation. If severe primary hæmorrhage has already occurred on the battlefield, most stringent measures must be taken to remove all dead and infected tissue, and every energy directed towards sterilisation of the wound after excision, as these patients possess but little resistance to infection, and secondary hæmorrhage is very apt to occur if the wound after excision again becomes infected to any considerable degree.

It is quite justifiable and better practice to wait in cases which show concealed hæmorrhage in such situations as the limbs and root of the neck. We are convinced on this point, as we have now been concerned in many of these cases, and have seen the results of immediate and delayed operation. The result of waiting is usually the formation of a false aneurysm. If a large artery is involved, the collateral circulation has a chance of establishing itself, the extravasated blood is in great part absorbed, and there is far less risk of hæmorrhage in late than in early operation. These cases rarely become infected, and without exception the swelling in the limb from extravasated blood has subsided and never caused serious interference with the circulation in the part of the limb below the lesion.

The difficulties of early operation in cases of concealed hæmorrhage are well known to surgeons who have worked at a casualty clearing station. Appalling hæmorrhages have resulted while operating upon wounds about the neck, and on more than one occasion the patient has died on the operating-table. Equally difficult and tedious at this stage are operations for ligature of the posterior tibial artery, the interosseous arteries of the forearm, etc. The wounds occasioned by the operation are very prone to become infected, and too often a secondary hæmorrhage follows. We therefore strongly recommend immobilisation of the limb and the adoption of the principle of wait and see, for we can speak from the results of both methods of treatment.

Treatment of Aneurysm.—Aneurysmal varix and varicose aneurysm must be treated by excision. The different operations are described in

most surgical textbooks, and need not be repeated here. We have always employed the method of complete excision, and have not had recourse to proximal or distal ligature or the methods recommended by Matas. It is important to be sure that the peripheral circulation is adequate before excision is performed, and we have usually employed proximal compression of the affected artery for a few days prior to operation.

False aneurysms show a marked tendency to spontaneous cure. This has frequently happened. Consequently the surgeon should not be in a hurry to operate. The false sac gets gradually smaller, and in a number of cases eventually becomes obliterated. Two cases of aneurysm of the intracranial part of the internal carotid artery took this course. Case 1, quoted above, on leaving hospital for England showed a small tumour that was steadily getting less, and we have seen spontaneous cure occur in a number of cases of false aneurysm affecting the large arteries of the limbs. Should the aneurysm persist, be causing pain or show signs of increasing in size, it should be removed by complete excision. We have now performed ten operations for excision of false aneurysm ; all healed by primary union, and in no case did gangrene follow. The important point in the conservative treatment of false aneurysm is absolute immobilisation of the part. If the limb be allowed to move, there is not only the risk of emboli to be feared, but the false sac may get larger and suddenly rupture.

Should the aneurysm be pressing on nerves and causing pain, proximal pressure should be given a fair trial before excision is decided upon.

Wounds of the Peripheral Nerves.

Wounds of the peripheral nerves are either contusions, lacerations, or partial or complete divisions. A nerve may be injured at any point in its continuity, and upon the particular point implicated will depend the incapacity.

Injuries of nerves often accompany injuries of the large arteries and veins, and a lacerated wound involving a large area of skin and fascia will implicate any cutaneous nerves which normally lie within the wounded area.

Large lacerated wounds which have been allowed to heal by granulation often incorporate cutaneous nerves in the scar tissue, causing much pain and suffering, and nerve trunks may become involved in the scar tissue of a deep wound which has been allowed to granulate, or in the callus of a uniting fracture, thus causing paralyses of the muscles it supplies and loss of sensation in the areas of skin to which it is distributed.

The nerves that will be referred to are those which mostly concern the orthopædic surgeon, and injury of which is associated with the greatest degree of disability. These are the nerves of the extremities.

Nerve injury may or may not be associated with pain or acute hyperæs-

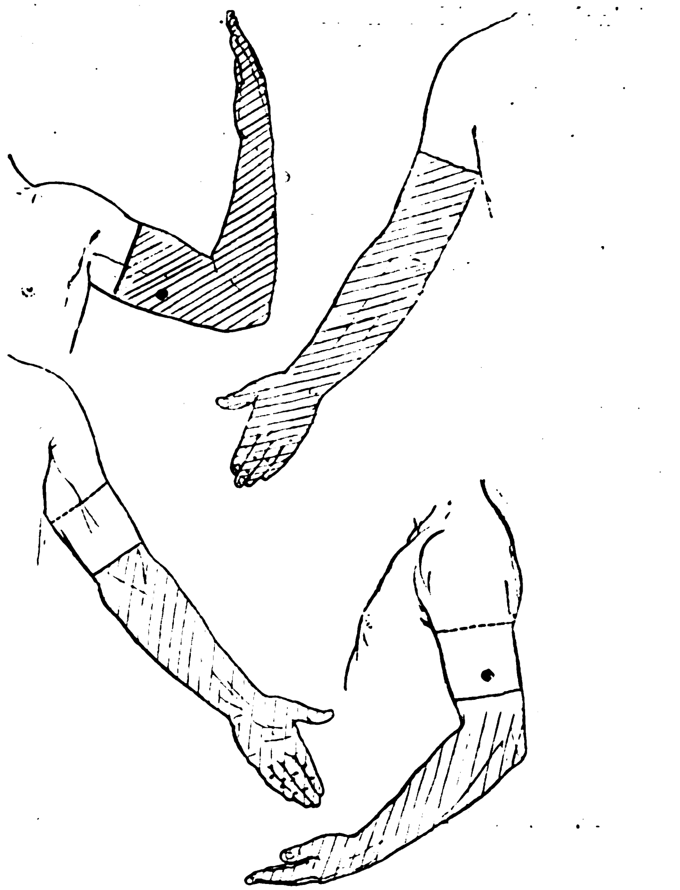

FIG. 351.—Musculo-spiral paralysis and hysterical "sleeve" anæsthesia.

14115 Sgt. B——, K.O.R.L.
Wounded 19, 9, 17.
Admitted 20, 9, 17.
Perforating gunshot wound of left upper arm caused by high explosive.
Left musculo-spiral palsy and hysterical "sleeve" anæsthesia.
Wounds all healed satisfactorily.
Wound of entry middle of outer side of arm just below insertion of deltoid; wound of exit ½ inch higher up.
23, 9, 17: Flexion of fingers and thumb exceptionally feeble and tremulous. Can extend interphalangeal joints of fingers by interossei and not by the long extensors. Complete paralysis of long extensors of wrist, fingers, and thumb. To pin-prick there is "sleeve" anæsthesia to lower border of pectoralis major, and to cotton-wool there is anæsthesia to 3 inches below this.
DIAGNOSIS.—*Combined functional and organic injury.*
1, 10, 17: To faradism, the biceps and triceps respond well; also flexors and pronators. No reaction in extensors of wrist, fingers, or thumb, nor in the supinator longus. Interossei and all intrinsic muscles of hand act normally.
15, 10, 17: To pin-prick, "sleeve" anæsthesia extends to horizontal level ½ inch below wound of entry—*i.e.*, it has receded several inches down the limb since 23, 9, 17. Cotton-wool anæsthesia to same level.
17, 10, 17: Incision to musculo-spiral nerve, which was exposed for 2 to 3 inches above and below track of missile, and found to be apparently normal.

thesia in the area which the nerve supplies. Pain has been frequently found to be associated with a partial tearing or a complete penetration of the nerve trunk. One case associated with a partial division of the sciatic nerve had constant pain of a burning and stinging kind alternating with pain shooting from the foot up the limb. The skin of the toes and foot became shiny and showed trophic changes. The pain was so intense and continuous that it became unbearable, and the patient started to go downhill for want of sleep. The sciatic nerve was exposed through an incision over the wound, when the nature of the lesion was discovered. The proximal end of the nerve, where it had been partially divided, was swollen and bulbous. The nerve was cleanly divided, the bulbous enlargement was excised, and the divided ends sutured. The relief of pain was immediate, and the wound healed *per primam*. The patient was heard of one year later, and he reported some slight amount of sensation and movement in the parts concerned.

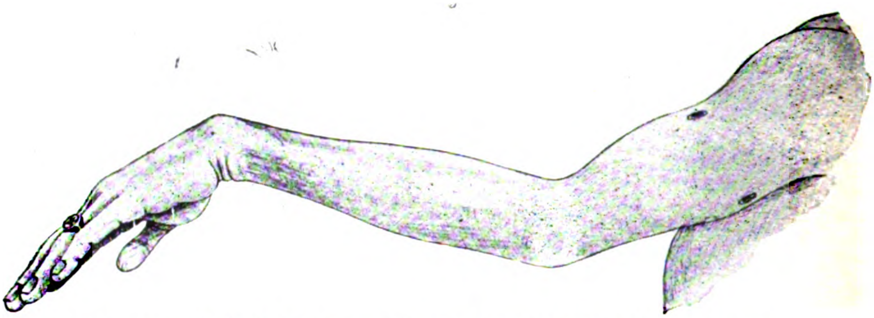

FIG. 352.—Wrist-drop in a case of contusion of the musculo-spiral nerve.

Similar symptoms occurred in another patient who had been wounded in the forearm. Intense and unbearable pain persisted in the hand and forearm, which prevented sleep. The median nerve was exposed, and found to be cleanly penetrated. A small piece of the nerve including the wound was excised and suture performed. Relief of pain was complete; the wound healed *per primam*, but we were unable to trace this patient after the sixth month following operation. At this date there was no return of sensation.

Many wounds implicating nerves, on the other hand, give rise to complete anæsthesia and analgesia in the parts of the skin they supply. The areas of anæsthesia and analgesia usually correspond to those supplied by the particular nerve involved, but occasionally the anæsthesia is of the "sleeve" variety. This is well illustrated in the case illustrated (see Fig. 351). This particular patient showed the reaction of degeneration on two successive occasions in the muscles supplied by the musculo-spiral nerve. On exposing the nerve it was found that its continuity was not destroyed, and it appeared to the naked eye normal. Recovery followed ten weeks after injury.

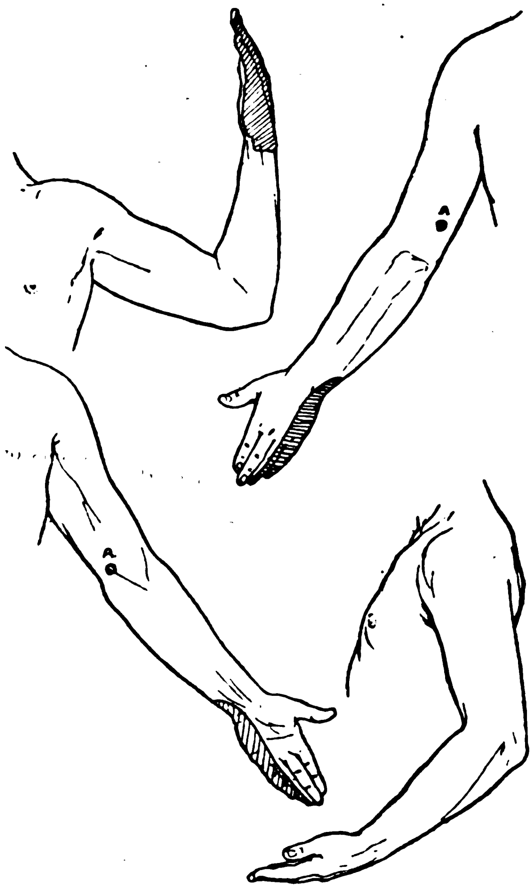

FIG. 353.

Shaded areas of anæsthesia and analgesia. *A* is position of wound.

Second-Lieut. ——, Berks Regt.
Wounded 8, 5, 17.
Admitted 9, 5, 17.
Through-and-through wound of upper and inner arm caused by bullet. Wound healed without operation.
Hyperextension of proximal phalanx of ring and little fingers, with flexion of terminal phalanges, producing the claw condition.
Complete anæsthesia and analgesia over the areas marked.
On attempting to hold and pull upon a flat object with the first finger and thumb, the short flexors of the thumb are used instead of the adductors, and the thumb becomes flexed, as shown in diagram.
Paralysis of interossei and lumbricales, with wasting of the muscles of the hypothenar eminence.
Fan movements of fingers impossible in inner two digits.
Adductors of thumb not working, as shown in diagram.
Reaction of degeneration in flexor carpi ulnaris and intrinsic muscles of hand.
Nerve exposed at site of lesion, and no breach of continuity or any obvious lesion found.

Paralysis of the muscles supplied by an injured nerve, with loss of sensation in the classical areas of skin supplied by the nerve, may be present; and yet the continuity of the nerve may not be in any way destroyed. This phenomenon is shown in the case illustrated (see Figs. 353, 354). In this particular case, although the reaction of degeneration was present in the muscles supplied by the ulnar nerves, yet to the naked eye, the nerve appeared normal when exposed. Recovery followed three months after injury.

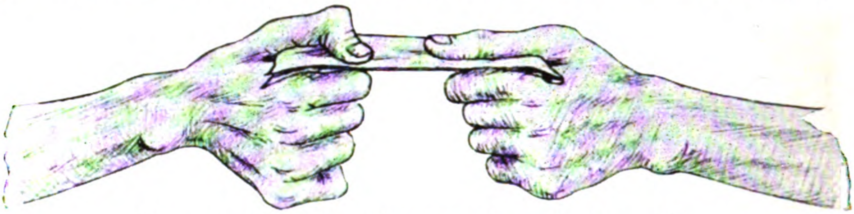

FIG. 354.—Paralysis of ulnar nerve the result of contusion.

Note the flexion of the thumb of the right hand. The adductors of the thumb are paralysed; consequently the muscles supplied by the median nerve are used.

The Brachial Plexus may be damaged as the result of gunshot wounds about the root of the neck. The nerve trunks most frequently involved

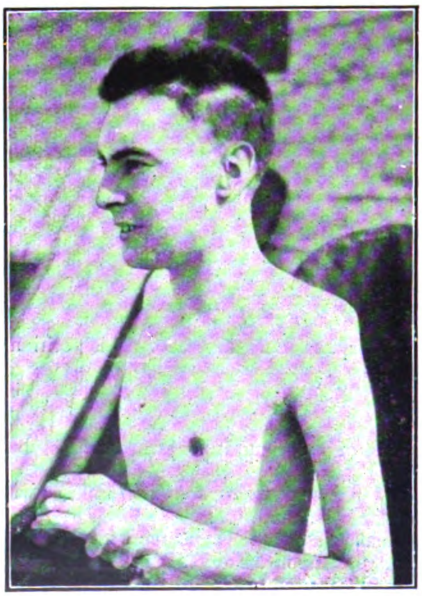

FIG. 355.—Paralysis of the fifth and sixth cervical nerves resulting from a gunshot wound of the root of the neck, and complicated by a false aneurysm of the subclavian artery.

Note the wasting of the deltoid and of the preaxial group of muscles.

are those of the fifth and sixth cervical. The symptoms are those of preaxial palsy (Erb), with paralysis and wasting of the deltoid (see Fig. 355).

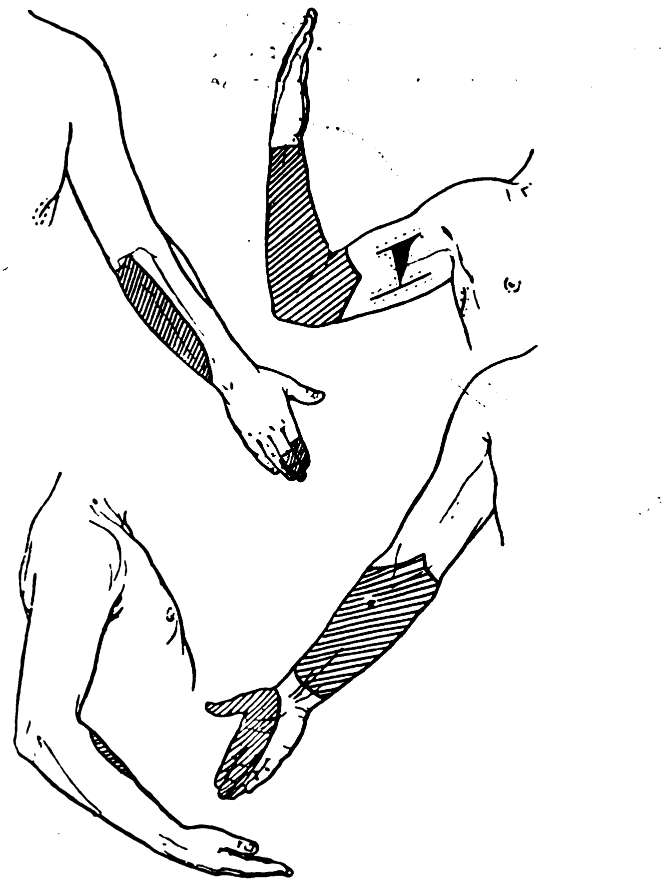

FIG. 356.

Shaded areas are those of anæsthesia and analgesia, which coincide. Black area shows the wound that has for most part been sutured.

87240 Gnr. N——, R.G.A.

Entrance wound in chest in front of right arm just below anterior axillary fold. Missile did not penetrate chest.

Entrance and exit wounds in arm. Entrance on inner side at junction of upper and middle thirds of arm. Lacerated exit wound about 4 inches above external condyle.

Operation at casualty clearing station. Removal of foreign body; inlet and exit wounds of arm excised and joined, necessitating division of biceps. *No divided or injured nerve was to be seen in the dissection. The hand feels numb over the middle and ring fingers.*

28, 9, 17 : Wounds in both situations sutured.

2, 10, 17 : Patient up.

6, 10, 17 : *Evident involvement of median nerve.*

15, 10, 17 : *To pin-pricks*, anæsthesia is present in median nerve area in palm of hand and fingers; also in dorsum of two terminal phalanges of median digits.

To cotton-wool, sensation lost over same area.

Joint sense normal in all the digits.

Pressure sense lost in anæsthetic area.

Forearm.—Widespread anæsthesia and analgesia of forearm both back and front, excluding territories of external cutaneous and radial nerves. Joint sense normal at wrist. *Biceps contracts feebly*, triceps good. Supinator longus good; pronation possible only to middle position. Can flex the two ulnar digits only. Can extend wrist, fingers, and thumb, and can adduct thumb. Wasting of muscles of thenar eminence. That is to say, *there is complete median palsy, motor and sensory, together with widespread sensory affection in internal and external cutaneous nerves.*

The Musculo-Spiral Nerve may be damaged either directly by a missile or as a complication of a fracture involving the shaft of the humerus. Wrist-drop is the important sequel (see Fig. 352).

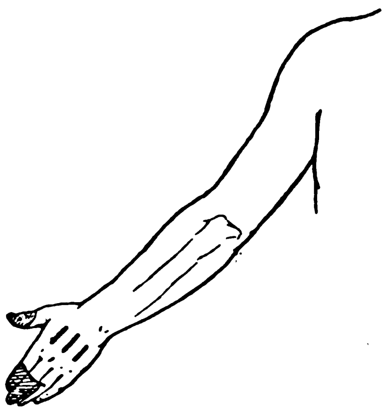

FIG. 357.
Shaded areas are those of anæsthesia and analgesia. Thick black lines are those of incisions.

Second-Lieut. J——, R.F.C.

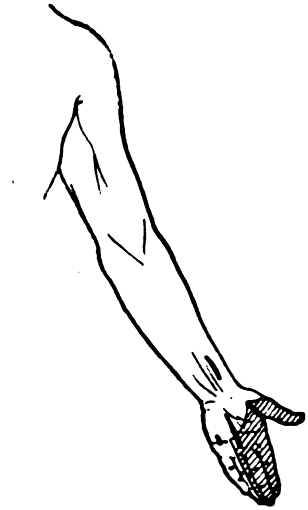

FIG. 358.—Involvement of median nerve in the palm of the hand.

The Ulnar Nerve may be injured as the result of wounds of the arm or forearm. A typical case is illustrated in Figs. 353 and 354.

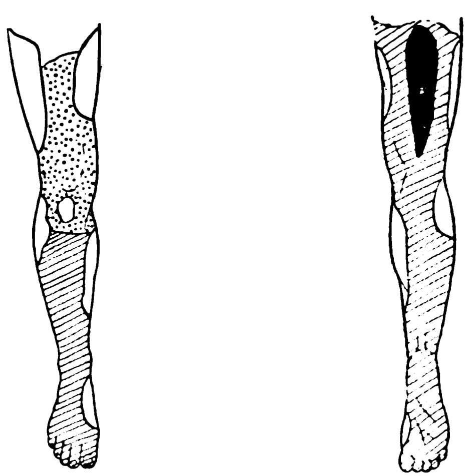

FIG. 359.
Shaded areas are those of anæsthesia and analgesia. Dotted areas are those of dim sensation to cotton-wool and pin-prick.

2891 Pte. D——, S. Lancs. Wounded 31, 8, 17. Admitted 3, 9, 17.

The Median Nerve may be injured in the upper arm, forearm, or at the wrist (see Figs. 356, 357).

The Sciatic Nerve may be implicated in any wound involving the buttock or thigh. A typical case is shown in Fig. 359.

The External Popliteal Nerve.—Damage to this nerve usually complicates wounds involving the neck of the fibula, the knee-joint or the

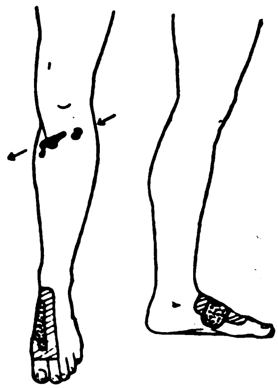

FIG. 360.—Foot-drop.

Shaded area is that of analgesia. Dotted area is that of anæsthesia. Black area about knee is wound caused by high explosive.

Second-Lieut. D——, R.F.C.
Wounded 24, 6, 17.
Admitted 26, 6, 17.
Wound caused by high explosive whilst flying.
Hæmorrhage very severe, causing profound collapse. Anterior tibial and peroneal arteries divided. Knee-joint widely opened from below, and communicating with the wound.
Carrel-Dakin dressing.
26, 7, 17 : Movement in knee, and up on crutches.
11, 9, 17 : Secondary suture performed. Bacterial count 1 per field.
20, 9, 17 : Sutures out, wound healed, except a small portion communicating with cavity in bone.
28, 9, 17 : To pin-pricks there is analgesia of area of dorsum of foot shown in diagram.
To cotton-wool the area of anæsthesia is about 1 inch less than that of analgesia, except at intervals, where it overlaps for a short distance.
The deep pressure is normal compared with healthy foot. Joint sense normal in all the toes.
No voluntary contraction in tibialis anticus, long extensors of the toes, and peronei muscles. Can invert the foot by means of the tibialis posticus muscle.
Left ankle-jerk just present, but less than the right.
8, 10, 17 : Subjective tingling in the foot dorsum for last three days. Anæsthesia as before. To faradism the calf muscles react briskly, also the tibialis posticus.
R.D. external popliteal nerve present.
1, 1, 18 : Full range of movement in ankle returned. Sensation now normal, and patient walking about with normal joint.

thigh (see case illustrated by Figs. 360, 361). Drop-foot is a result of injury to the external popliteal or anterior tibial nerve.

The Posterior Tibial Nerve is most frequently damaged in the part of its course below the malleolus of the tibia ; it is rarely injured in the calf of the leg.

An injury of the great auricular and spinal accessory nerves is shown in Fig. 363.

TREATMENT.—Nerves that in lacerated wounds are seen to be divided should be sutured at the time that the wound in the soft parts is excised.

FIG. 361.—Drop-foot resulting from injury of external popliteal nerve.

If this is impossible owing to destruction of a considerable portion of its continuity, then the gap should be bridged with a few strands of catgut. It is useless to attempt approximation of the divided ends of a nerve

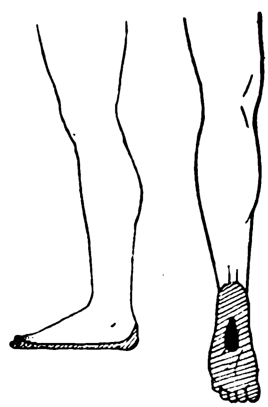

FIG. 362.—Wound involving posterior tibial nerve just below internal malleolus. Shaded areas are those of anæsthesia and analgesia. Black area that of pronounced hyperæsthesia and hyperalgesia. Continuity of nerve not wholly destroyed.

when there has been loss in its continuity so long as the wound is infected ; hence sterilisation of the wound and secondary suture should be the surgeon's first aim, leaving any subsequent operation on the nerve until later, when the wound is healed with the minimum amount of scar tissue.

Small perforating wounds of the extremities which are followed by paralysis of nerves call for expectant treatment, although the reaction of degeneration and a classical anæsthesia be present in the muscles and skin supplied by the nerve. Too often at operation, nerves apparently divided have been found to be intact, and restoration of function has followed within an interval of three months. For cases such as these,

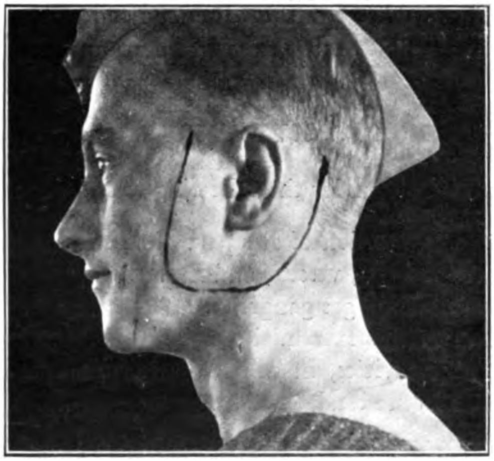

FIG. 363.—Injury of the great auricular and the spinal accessory nerves. Winged scapula was present, and anæsthesia of area shown. Note position of entry and exit wounds.

massage and electrical treatment should be employed, after the correction of any obvious deformity in the shape of dropped wrist or dropped foot, for four or five months. If at the end of this time the symptoms still persist, then it is justifiable to cut down on the injured nerve, and investigate the damage done.

Perforating wounds of nerves associated with pain which disturbs sleep and trophic changes in the skin require operative treatment, and this has been referred to already.

CHAPTER XXV

AMPUTATIONS

AMPUTATION is called for under the following conditions:

(1) Hopeless mutilation of any part of a limb involving irreparable damage to bone, vessels, and nerves.
(2) Acute spreading gas gangrene.
(3) Wounds of the extremities, especially those implicating bone and joint cavities, in which septicæmia is either threatening or has become established.
(4) Repeated secondary hæmorrhage.
(5) Wounds involving such excessive loss of continuity in a bone as will leave a flail and useless limb.
(6) Gangrene other than gas gangrene resulting from any cause.

Limbs that are hopelessly mutilated are beyond human aid, and amputation is inevitable. Amputation for conditions resulting from sepsis have been numerous in the past. To-day it seems that the tide is turning, for amputation has become far less frequent since early excision of the wound followed by an efficient sterilisation has been practised. To-day many limbs are saved that eighteen months ago would, without hesitation, have been submitted to immediate amputation. Success in these cases undoubtedly lies in early excision and rapid sterilisation of the wound, and we have found no more satisfactory method of accomplishing this than that recommended by Carrel and Dakin.

A single series of 109 cases of amputation include 32 performed at a casualty clearing station and 77 at a base hospital in the East.

Of the 32 performed at the clearing station, 20 were concerned with the lower extremity and 12 with the upper extremity.

Amputation was necessitated by—

(1) Irretrievable damage of large vessels, bone, and nerves.
(2) Extensive mutilation of soft structures.
(3) Gangrene.

Seventy-seven amputations performed at a base hospital include—

	Cases
(1) Compound fracture of the pelvis with severe comminution of the upper third of the femur	1
(2) Advanced gas infection of the thigh	14
(3) Gangrene of the leg with extensive comminution of bone ..	12
(4) Irretrievable damage of the tarsus with gangrene of the foot	3
(5) Disarticulation at the hip-joint for gangrene	5
(6) Gunshot wounds of the knee-joint	15
(7) Gunshot wounds of ankle and tarsal joints, with severe comminution of bone	5
(8) Gangrene of the upper arm requiring disarticulation at the shoulder-joint	5
(9) Compound comminution of forearm, carpus, and metacarpus	4
(10) Thirteen cases of amputation transferred from other hospitals	13
Total	77

Choice of Operation.

When amputation is inevitable, the choice of operation must be governed by circumstances. It is rarely possible to perform the classical amputations recommended in textbooks, as so few cases are suitable.

Experience gained at a busy casualty clearing station in France, suggested the following conclusions :

1. If a wounded man is very collapsed as a result of shock and hæmorrhage, and if immediate amputation is necessary, a flush or guillotine amputation should be performed, if possible, through healthy tissue. If this is impossible, it must be conducted through infected tissue. The method has two advantages in that it—

(*a*) Is rapid and causes the minimum of shock, and can if necessary be performed under nitrous oxide and oxygen anæsthesia.

(*b*) Leaves the minimum surface of exposure for infection and septic absorption.

It possesses the disadvantages of leaving an open amputation stump, and the necessity of a higher amputation later on. The ends of the divided nerve trunks are apt to be left exposed, as is also the ligatured end of the artery.

2. If time permits and the patient's condition warrants it, and especially if the amputation can be performed through apparently sound tissue, then flaps can be fashioned from whatever tissue is available. If possible, equal and long anterior and posterior flaps are preferable. After thoroughly cleaning and shaving the skin, a tourniquet is applied. Long anterior and posterior

skin flaps are now fashioned and reflected (see Fig. 364). A guillotine division of the muscles is next performed, and both muscle and periosteum are retracted (see Fig. 365). The bone is next sawn through and

FIG. 364.—Amputation through middle third of thigh.
Skin flaps cut and reflected.

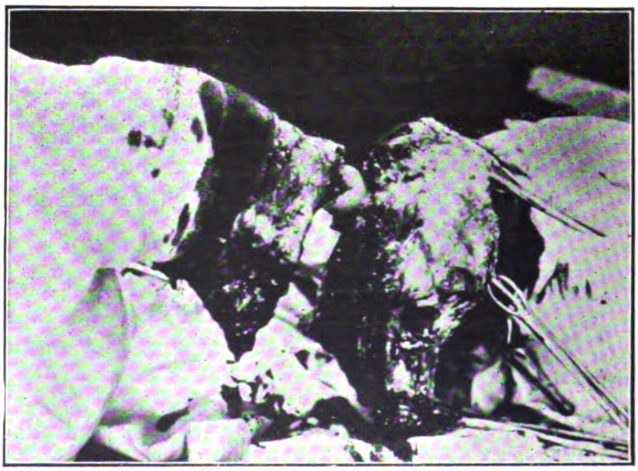

FIG. 365.—Same case as Fig. 364.
Guillotine amputation through muscle.

the amputated limb removed (see Fig. 366). The cuff of periosteum is next stitched over the divided end of the bone, and all divided vessels ligatured. The main artery should be secured with a double ligature (see Fig. 367), and the nerve trunks drawn down and cut short.

The muscles are approximated by one or two sutures of catgut to obliterate all dead space (see Fig. 368), and the skin is finally sutured

FIG. 366.—Third stage of amputation.
Note cuff of periosteum turned back.

FIG. 367.—Same case as Fig. 364.
Cuff of periosteum stitched over divided end of bone ; the vessels have been ligatured and the tourniquet removed.

with silkworm-gut (see Fig. 369). Throughout the operation the wound surface is swabbed with flavine, and before applying the dressing 3 or

4 drachms of flavine (strength 1 in 1,000) are injected between the sutures in the skin into the tissues of the stump. A dressing and splint are then applied, and the patient returned to bed with the stump elevated.

FIG. 368.—Approximation of divided muscles.

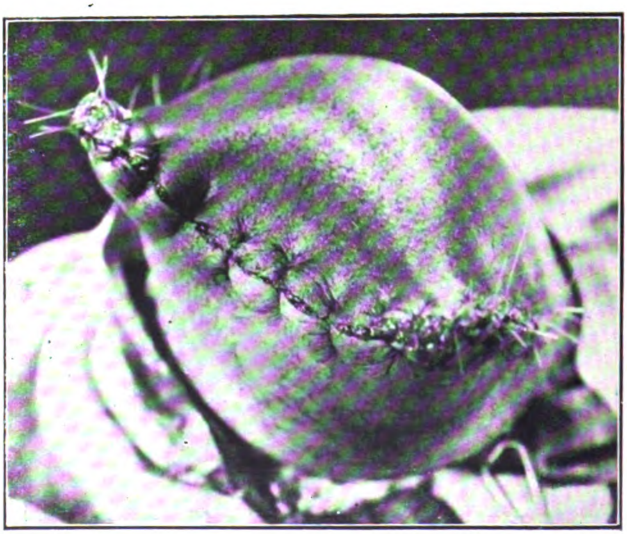

FIG. 369.—Shows amputation completed.

If the amputation has to be performed through infected tissue, the flaps are stitched widely open and a Carrel's dressing applied. As soon as the stump is sterile, secondary suture is performed (see Fig. 370).

3. We have now performed a number of amputations through infected tissue, and have closed the stump by suturing the flaps over Carrel's tubes. Two-hourly instillation of the antiseptic (hypochlorite) has been carried out, and in the majority of cases the stump has healed by primary union. We would recommend this procedure at the field ambulances for cases in which operation can be undertaken at an earlier date following injury, and consequently at a time when infection is still slight and limited to the tissues of the wound. This will not only save time and expenditure of labour and dressings, but it will also save the patient much pain and a second operation later on for closing the stump.

FIG. 370.—Carrel's method of disinfecting an open amputation stump. The skin flaps have been stitched back. A guillotine amputation has been performed through the muscles.

Amputations performed in the trenches, at the field ambulances, or the advanced dressing stations, usually consist in dividing the remaining muscles or tendons which still hold the limb on. Many cases arriving at a casualty clearing station are in a most profound condition of shock and collapse, resulting from hæmorrhage or from the imperfect immobilisation of the wounded limb during transport, and the consequent pain. The shock occasioned by a compound comminuted fracture of the femur is well known, but if in addition to the fracture there is a superadded virulent infection of the soft parts, together with the unavoidable shaking during transport, the general condition of patients so afflicted by the time they reach the casualty clearing station is often desperate; hence it is easy to realise the number of guillotine amputations which must reach a base hospital.

Subsequent History of Open Amputation Stumps.

All open amputation stumps are infected from the beginning; hence it is of the utmost importance to start their sterilisation at once. A Carrel-Dakin dressing should be applied immediately the amputation is completed. Guillotine amputation stumps are exceedingly prone to secondary hæmorrhage, as the ligatures on the main vessels, if the stump is infected, hold only for a very short time. Secondary hæmorrhage has occurred as early as the fifth day and as late as the twelfth day after the amputation has been performed.

Secondary hæmorrhage and its treatment have already been referred to. We recommend anterior and posterior flaps for all amputations whenever they can be conveniently fashioned, but the surgeon must be prepared to make use of whatever flap he can get. Amputations through the upper arm are quickly and easily performed by the circular cuff amputation. It is always advisable to apply extension to open amputation stumps at the earliest possible time in order to prevent retraction of the soft parts.

Secondary Suture of Open Amputation Stumps.

Secondary suture in the case of guillotine amputation stumps is a difficult procedure because—

(1) Muscles and skin have become retracted.
(2) The smaller arteries in the muscles of the stump are both numerous and enlarged, rendering reamputation difficult.
(3) There is always septic sequestration going on in the divided end of the bone.

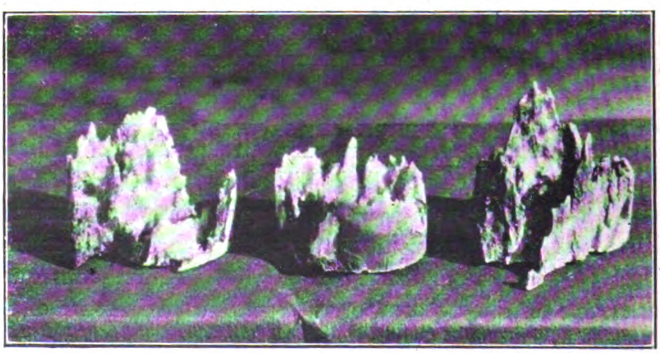

FIG. 371.—Sequestra that have separated from the ends of amputation stumps during the fifth week following amputation.

Retraction of the skin can in great part be prevented by extension applied to the skin of the stump during sterilisation. Whenever possible, we have waited until the sequestrum from the end of the bone has sepa-

rated naturally before performing secondary suture, and this occurs from the fourth to the fifth week after the amputation has been performed (see Fig. 371).

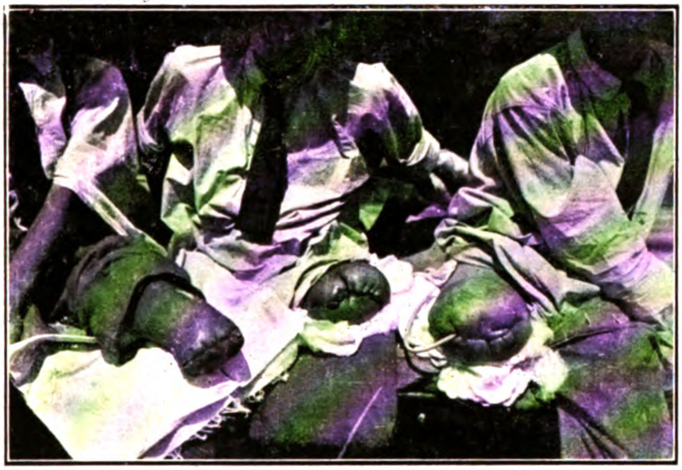

FIG. 372.—Three cases of guillotine amputation after secondary suture.

FIG. 373.—Group of amputation cases in which the stumps have been sutured. In all these cases the stump has healed and the patients are ready to proceed to England.

When the stump is sterile and the sequestrum has separated, the soft parts are pushed back and separated subperiosteally from the bone. A piece of bone is removed of sufficient length to allow the skin to meet over

it. If extension has been applied to the stump from the beginning, this is usually possible. If, on the other hand, the skin has retracted, then reamputation with removal of more muscle must be undertaken.

The stump is now sutured, and one or two Carrel tubes are included.

If at the primary operation skin flaps have been fashioned and stitched back, removal of the bone is all that is required. It is important to make the skin flaps *as long as possible* at the primary operation. The sutures are removed at the end of the tenth or twelfth day, and the patient may get up at the end of a fortnight.

When guillotine amputation has been performed there may be considerable tension in the skin sutures. We have in this connection used the method advocated by Major Chapple, whereby the tension sutures are inserted through buttons or pieces of rubber tubing placed parallel to the line of suture. By this means not only the tension on the approximating stitches is relieved, but all dead space in the stump is obliterated.

In all cases requiring amputation conservatism must, of course, be practised and the greatest length of stump left.

Syme's amputation and amputations performed through the knee-joint have not proved a universal success in connection with war wounds.

Flush amputation through the knee-joint for severe wounds of the leg in desperate cases is a rapid procedure, for there are only the popliteal and sural vessels to ligature. Secondary suture in these cases is simpler, and can be undertaken earlier. The patella should always be removed at the primary operation.

CHAPTER XXVI

GUNSHOT INJURIES OF THE SPINE

THE spine may be injured as the result of wounds involving—

(1) The perivertebral soft structures only.
(2) The perivertebral structures and vertebræ.
(3) The perivertebral structures, vertebræ, and spinal cord.

Gunshot wounds of the perivertebral soft structures only, may give rise to symptoms of injury of the spinal cord, and as a result of such wounds hæmorrhage of varying degree has not infrequently occurred within the spinal canal. The more common sequel, however, to injuries of this kind is a state of spinal concussion, although this latter condition may become established in the absence of any visible wound through such an event as the burst of a shell in the immediate vicinity of the individual affected.

Symptoms may range from paresis to complete paralysis, and often associated with them are psychic phenomena. Instances of this kind are true cases of shell concussion, and they must not be confounded with that heterogeneous collection of cases showing a diverse variety of symptoms which were formerly grouped under the title of "shell shock." Some authorities will deny that psychic neuroses and wounds can coexist in the same individual, or that even a true spinal concussion can be complicated by psychic phenomena. This has not been our experience either in the line or at the casualty clearing station. We admit that while coexistence of the two conditions in the same individual is comparatively rare, yet in an appreciable percentage of cases they do occur together.

One instance may be quoted :

Lieut. —— during an engagement was hit in the leg. He was brought to the regimental aid post ; his wound was dressed, and he was put on a stretcher to await evacuation. During this time other wounded were receiving attention, there was considerable disturbance going on outside, and shells were bursting near by. This officer, despite the severity of his wound, suddenly got up, protested murder, drew his revolver, and threatened to shoot everybody in the dug-out. He had to be forcibly restrained and tied to his stretcher. Half a grain of morphia was administered hypodermically, and his evacuation from the line was carried out as soon as the

shelling had ceased. Three months later he was still undergoing treatment for the psychic condition, and was reported to be improving.

This is but one example of many which came under our care while in trenches.

Wounds involving perivertebral structures and vertebræ may occur in the absence of injury to the spinal cord. Damage to the vertebral column may consist in fracture of the transverse processes, the spinous processes, the laminæ, or the bodies of one or more vertebræ. It is not of rare occurrence to see a missile lodged in the body of a vertebræ without giving rise to symptoms of cord injury. Fracture of the spinous processes is not uncommon; fracture of the laminæ is usually associated with symptoms of pressure upon the spinal cord, while fracture of the transverse processes may implicate either the nerve roots or the nerve trunks as they emerge from the intervertebral foramina.

Fracture of the transverse processes of the cervical vertebræ is apt to be complicated by injury of such important structures as the vertebral artery and vein, the nerve trunks of the brachial plexus, or of the fourth cervical (phrenic nerve).

Severe hæmorrhage which is difficult of control may take place from wounds in this region, whilst paralysis of the diaphragm as a result of injury of the phrenic nerve is an exceedingly grave complication.

The spinal cord may be injured as the result of—

(1) Pressure exerted upon it by a missile or a depressed piece of bone.
(2) Pressure exerted upon it by an extrathecal or an intrathecal hæmorrhage.
(3) Partial or complete division of the cord by the missile.

Wounds involving the cord may range from small penetrations or perforations to wounds of the most ghastly description. Fortunately, many of the more severe cases die a painless death in the line. Apart from their terrible nature, these wounds have presented some points of interest. The following are one or two examples:

Case A.—Pte. —— was completely decapitated by a trench mortar, the body being flung over the parapet by the force of the explosion, whilst the head remained in the trench bottom. An examination almost directly after it had happened showed conjugate deviation of the eyes to the right, there was a coarse irregular nystagmus, the facial muscles were twitching, and the corneal reflex was present. The light reflex was not tried. The twitchings of the facial muscles persisted after the corneal reflex had disappeared, which, as far as we could reckon, was about three minutes after decapitation.

Case B.—Pte. —— was completely cut across at the level of the second or third dorsal vertebra by a large piece of high explosive shell shaped like a knife-blade (longer than the blade of an ordinary bread knife and much

heavier.) The same phenomena were observed in the face and eyes. Examination of the trunk showed the knee-jerks to be present and distinctly brisk. Pinching the inner side of the thigh caused the corresponding leg to be drawn up, and both urine and fæces were voided. Owing to circumstances, the plantar response was not tested, neither was the presence or absence of ankle clonus ascertained.

Case C.—Pte. —— was wounded by a piece of high explosive shell which carried away a large portion of his back in the middle dorsal region. The spinal column and cord were "mushed" (no other word describes the condition) over an extent of about three vertebræ, and there was severe and uncontrollable hæmorrhage taking place. To all appearances the man was dead, for there was no attempt at voluntary movement above the lesion and respiration had ceased. An examination directly after the injury showed exactly the same findings as in Case B.

It seems, therefore, that a complete lesion of the spinal cord is not followed immediately by loss of the deep reflexes, and that accessory centres are probably present in the cord, allowing of muscular response to cutaneous stimuli. We regret that circumstances did not permit of investigation of the plantar response and ankle clonus.

Wounds of the spine in the dorsal and lumbar regions may be complicated by injury of the thoracic or abdominal viscera.

If the thorax is involved, the lungs, heart, or great vessels may be wounded. An injury of the heart or the great vessels is practically always rapidly fatal. Wounds of the lung under these circumstances are usually severe, as spicules of bone are apt to be carried forward by the missile into its substance, so causing a greater degree of laceration.

If the wound involves the abdomen, any of the abdominal viscera may be implicated, though perhaps the most common in this connection are the kidneys. If the aorta or any of the larger vessels are wounded, death usually follows rapidly ; hence these cases rarely leave the battlefield.

The spine, on the other hand, may be injured by a missile which first enters the abdominal or thoracic cavities, and this event has already been referred to in other chapters dealing with wounds of the thorax and abdomen.

Lastly, wounds of the spine may be complicated by multiple wounds elsewhere.

Diagnosis.

An early and correct diagnosis of the nature of the injury is essential. The main points to consider are—

(1) The presence or absence of a visible wound.
(2) The condition of the motor and sensory functions in the parts below the lesion immediately after the wound has been inflicted.
(3) The level of the zone of hyperæsthesia.
(4) The condition of the sphincters.

(5) The effect of lumbar puncture on the symptoms and the character of the cerebro-spinal fluid.
(6) The result of a skiagram taken in two directions to show the position of the missile and the nature and extent of the damage to bone.

The regimental medical officer can be of the greatest possible assistance in giving a very brief account of the wounded man's condition directly after he is hit, because it is extremely important to know *whether loss of sensation and voluntary movement below the lesion was instantaneous, or whether an interval of time existed, however short, in which sensation of any kind was present or voluntary movement possible ;* for by the time the patient reaches a casualty clearing station both paraplegia and paranæsthesia may be complete. Information furnished by the early condition of the reflexes is of little use in the diagnosis of spinal injury.

The level of the zone of hyperæsthesia will furnish information as to which segment of the spinal cord is involved.

Paralysis of the sphincters (especially the deep sphincter ani) usually points to a definite lesion of the cord, though the sphincters may become temporarily paresed in cases of severe spinal concussion.

Lumbar puncture will show—

(1) Whether the cerebro-spinal fluid is under tension.
(2) Whether the fluid is clear, blood-stained, or purulent.
(3) Whether its evacuation brings about any change in the symptoms.

An X-ray will show the presence of a missile or a depressed piece of bone pressing upon the cord.

Spinal Concussion.—Paresis of the limbs, with headache and perhaps vomiting, inability to urinate, necessitating the use of a catheter, the presence or absence of psychic phenomena, a slow pulse and subnormal temperature occurring in the absence of an open wound, point strongly to a condition of spinal concussion. A lumbar puncture showing clear cerebro-spinal fluid under tension will help to confirm the diagnosis, and with relief of the pressure there is almost invariably an immediate relief of the symptoms.

Paraplegia.—Complete paralysis with anæsthesia of the parts below the lesion may be due to pressure exerted on the cord either by a hæmorrhage or by a foreign body in the shape of a missile or depressed piece of bone, or to a partial or complete division of the cord. It is in cases such as these that the early history is so valuable. If an interval of time did exist after reception of the wound in which the wounded man possessed sensation and a degree of voluntary movement in the parts of the body below the lesion, then either hæmorrhage or pressure exerted on the cord by a foreign body are the two possibilities. In the case of hæmorrhage the zone of hyperæsthesia is not well defined—in fact, it may be so indefinite as to

hardly exist—whereas anæsthesia or paræsthesia may extend to a higher level than that denoted by the injury. A lumbar puncture will reveal the presence of blood in the cerebro-spinal fluid, and its removal will often cause an amelioration of the symptoms, especially those relating to the sphincters. Both intrathecal and extrathecal hæmorrhage are usually associated with a rise of temperature and a slight increase in the pulse-rate. There is usually spasticity of the muscles below the site of injury.

Paraplegia, the result of pressure exerted on the cord by a foreign body, either in the form of a missile or a depressed fragment of bone, follows rapidly after the infliction of the injury. There is usually a definite zone of hyperæsthesia; paralysis and anæsthesia of the parts of the body below the lesion, with involvement of the sphincters, may or may not be complete; and symptoms are not relieved by lumbar puncture. Lumbar puncture may or may not show the cerebro-spinal fluid to be blood-stained, but it is always under increased tension, and an X-ray will confirm the nature of the damage done. In the absence of complete paralysis, there is spasticity in the muscles of the part of the body below the lesion, and this will depend in extent upon the degree of pressure exerted on the cord.

Paraplegia due to partial or complete division of the cord is *complete from the beginning*, and there is a well-marked zone of hyperæsthesia. The muscles of the part of the body below the lesion are flaccid, and there is complete loss of sphincter control. If the lesion be high up in the dorsal region, then abdominal distension and priapism may be present, though priapism is not uncommon in lesions involving the lower dorsal and upper lumbar segments.

Should loss of sphincter control with complete paralysis and loss of sensation of the parts of the body below the lesion be complicated by abdominal distension and priapism, the prognosis is extremely grave.

Complications.

Immediate.—

(1) Osteomyelitis of the vertebræ affected.
(2) Spinal meningitis.
(3) Acute myelitis of the cord.
(4) Retention of urine.

Remote.—

(1) Trophic phenomena in the form of pressure sores affecting the skin below the lesion.
(2) Cystitis, pyelitis, and pyelo-nephritis.
(3) Incontinence of both fæces and urine.

Osteomyelitis of the injured vertebræ has been of rare occurrence. Should it occur, however, the large veins both within and immediately without the spinal column (dorsal spinous venous plexus) become throm-

bosed, septic emboli become detached, and septicæmia or pyæmia follow. Infection may spread to the cord, giving rise to a condition of acute myelitis or spinal meningitis.

Spinal meningitis and myelitis occur as the result of the spread of infection from the wound to the meninges and cord. The pathology is the same as that of meningitis and encephalitis complicating penetrating wounds of the head. The subarachnoid space of the cord tends to become shut off by adhesions from the wound in the meninges, and thus the arrest of a general infection of the meninges may be effected.

When once a general infection of the meninges is established, spasticity of the limbs occurs, with retraction of the head and rigidity of the muscles of the back of the neck. Kernig's sign is early present. As the infection spreads upwards, the basal meninges become involved, vomiting, headache, and optic neuritis occur, and a squint may develop. The pulse becomes rapid and irregular, fever is present, and the patient dies comatose.

An examination of the cerebro-spinal fluid before death shows turbidity, and the microscope will reveal the presence in the fluid of pus and organisms.

Retention of Urine.—This is a most constant accompaniment of all spinal injuries, and calls for the use of a catheter six-hourly.

Trophic Sores occur at all points subjected to pressure, and in this connection most commonly affect the skin covering the sacrum, the great trochanters, and the heels. They may attain large dimensions, and, owing to the incontinent condition of the patient, they are practically always infected ; hence there is a degree of superadded toxæmia.

Cystitis and Pyelitis, when once established, are extremely grave complications, and are often the immediate cause of death.

Treatment.

A. **On the Battlefield.**—There is no actual treatment beyond dressing the wound to be undertaken here. The patient should be placed on a stretcher with a couple of blankets beneath him, and removed to the field ambulance with the least possible delay. A short note should accompany him, recording the presence or absence of sensation or voluntary movement directly after injury in the parts of the body below the lesion.

B. **At the Field Ambulance.**—All clothing should be removed, and a pyjama suit with bed-socks substituted. The patient should be laid on a stretcher with a soft mattress beneath him, in order to diminish pressure on and bumping of the paralysed parts during transit to the casualty clearing station. A catheter should be passed, if necessary, before he leaves this unit, and this must be carried out under the strictest aseptic precautions, and the time noted on the field card. Short notes as to the presence or absence of sensation and voluntary movements in the parts below the injury should be entered on the field card, and this should be attached to the

notes of the regimental medical officer. After administration of antitetanic serum, the patient should be given 20 grains of urotropine by mouth, and evacuated without delay to the casualty clearing station.

C. **At the Casualty Clearing Station.**—If there is a rush of work at this unit, it is inadvisable to attempt to deal with these cases. As a rule, there are operations in progress on highly infected wounds, there are many more urgent cases waiting for operation at the time, and the nursing and necessary attention that these patients require cannot be adequately given at this unit; hence, if possible, their immediate evacuation to the base is in every way desirable.

Urotropine (gr. xx.) should be administered by mouth, a short note as to the condition of sensation and voluntary movements in the parts below the lesion should be made, and affixed to those of the regimental medical officer and field ambulance. A catheter should be passed and the urine drawn off immediately before evacuation to the base, and the patient should travel on a stretcher with a soft mattress beneath him.

D. **At the Base Hospital.**—After an X-ray has been taken, the patient is at once put on a water-bed. An examination is now undertaken to ascertain the presence or absence of sensation and voluntary movements in the parts below the lesion, and the level of the zone of hyperæsthesia. The result of this examination is carefully compared with the notes of the regimental medical officer, the field ambulance, and the casualty clearing station. Nothing has so far been mentioned about the state of the reflexes, as in the early stages following a wound of the spine they are both variable and unreliable.

By the time the patient reaches the base hospital they are usually established, and are of assistance. An extensor plantar response with the presence of ankle clonus, spasticity, and exaggeration of the deep reflexes, point to organic injury of the cord.

Loss of the deep reflexes, total paralysis, and loss of sensation, with flaccidity of the muscles below the lesion; the loss of sphincter control, with priapism and abdominal distension, form a symptom-complex denoting a gross lesion of the cord, and the prognosis is extremely grave.

Should paresis or paralysis, with diminution or perversion of sensation, be present in the absence of a wound, and should there be headache with a slow pulse and subnormal temperature, the case is probably one of spinal concussion.

If rest in bed does not bring about a rapid improvement in the symptoms, lumbar puncture should be performed, and the cerebro-spinal fluid allowed to escape very slowly until the rate of drip from the cannula becomes normal. As much as two test-tubes full of fluid may be removed. Massage to the affected limbs should be daily carried out until recovery is complete, which usually takes from three to six weeks.

If the paralysis be due to hæmorrhage, and the X-ray shows the absence of a foreign body pressing upon the cord, and if the wound, as is often the

case, be small and penetrating or perforating, lumbar puncture should be performed and the wound left alone, unless it be inflamed. In the latter case it should be excised and opened up, and a Carrel-Dakin or flavine dressing applied. Rest in bed with lumbar puncture is often sufficient to effect a cure in these cases, and the missile can always be removed at a later date if necessary. It may be necessary to repeat the lumbar puncture, and in every case the fluid withdrawn should be carefully investigated bacteriologically.

Should the X-ray show the presence of a foreign body in the shape of a missile or a piece of bone pressing on the cord, then laminectomy must be undertaken. If the wound in the soft parts is situated at some distance from the middle line of the back, the incision should be made in the middle line. If, however, the wound is situated close to the mid-line of the back, then the laminectomy incision should be planned to include it, and by this means the wound can be excised. The free use of hot sterile cloths and adrenalin is sufficient to stop all hæmorrhage. When the wound in the vertebral column has been exposed, sufficient bone should be removed in order to expose freely the dura mater of the cord. Great care is needed here in order to preserve the newly formed subarachnoid adhesions. If the dura is intact, removal of the missile and the depressed piece of bone is all that is required ; but if the dura has been opened, it should be treated in exactly the same way as the dura mater of the brain—that is to say, bone should be removed until intact dura is exposed to an extent of ¼ inch all round the perforation.

The wound in the back should now be closed, but a tube should be left in extending down to the fracture of the vertebræ, but it must not in any way come in contact with the spinal cord.

Cases of gross lesion to the cord which show a missile or a detached piece of bone to be pressing upon it should receive similar treatment, for although this treatment proves often to be unsatisfactory, yet some brilliant results have been obtained by laminectomy in these cases.

Great care should be bestowed upon the backs and points of pressure of these patients. We have from the beginning always used the following preparation with success as a prophylactic against pressure sores :

Bismuth oxychloride	gr. xv.
Zinc oxide	gr. xv.
Oil of eucalyptus	℞x.
Castor oil	q.s.

Fiat pasta.

To be applied morning and evening after washing the skin with soap and spirit.

The greatest care possible should be exercised in the six-hourly use of the catheter, and every aseptic precaution taken.

These patients should as a routine be given urotropine (gr. xx.) three times a day.

Great care and cleanliness must be exercised in the case of patients with dual incontinence.

Bed-sores, when once they have formed, should be kept as clean as possible, and for a day or two hot fomentations applied frequently should be employed. When once the sores have cleaned up, scarlet-red ointment makes an excellent application.

Cystitis should be treated by lavage, and perhaps the best solution to use in this connection is half-strength eusol.

Spinal meningitis is best treated by repeated lumbar puncture combined with the use of an autogenous vaccine.

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Baillière, Tindall & Cox, 8, Henrietta Street, W.C.